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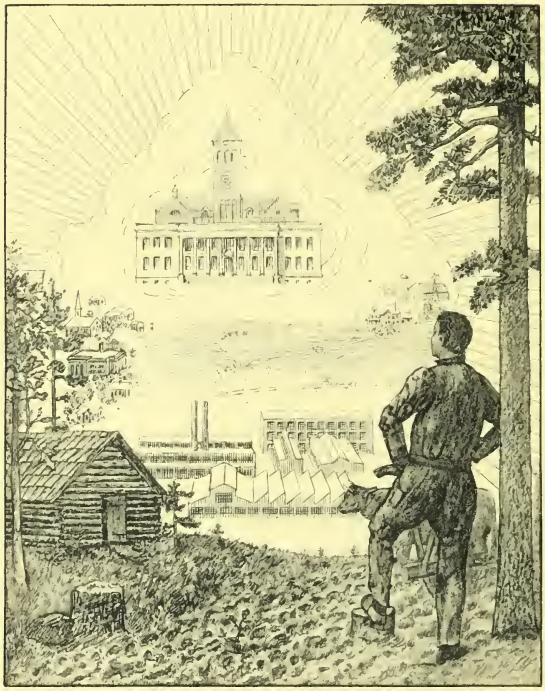

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WATER-SUPPLY PAPERS

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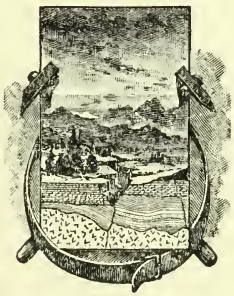

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Water-supply paper 315; Purification of public water supplies.
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Same 317; Geology and underground waters of Wichita region, north-central Texas.

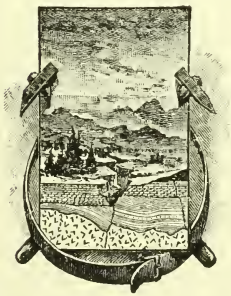
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 315

THE PURIFICATION OF PUBLIC WATER SUPPLIES

BY

GEORGE A. JOHNSON



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THE PURIFICATION OF PUBLIC WATER SUPPLIES.

By George A. Johnson.

INTRODUCTION.

This paper has been written in response to a strong demand by officials of municipalities and institutions and by interested citizens for a simple and direct statement of the principles and practices governing the purification of waters used for domestic purposes. The work is in no sense a treatise; it states the more vital features of the subject and seeks to indicate how best to deal with the various problems involved in water purification.

The manuscript was submitted by the author in July, 1911, and publication has been unavoidably delayed. The science of water purification progresses rapidly. Therefore the text is, in some relatively unimportant respects, behind the most approved practice of to-day.

POLLUTED WATER.

Polluted water, in the sense in which the term is used in connection with municipal water supplies, is water that contains sewage or industrial waste of such a character that if the water be used for drinking by man it causes or is likely to cause discomfort or actual disease. Pollution of this kind is the result of human processes, whether the polluting material be personal waste or waste resulting from industrial activity. It follows that wherever man lives the water draining from or passing through the land on which he dwells or works must in smaller or greater measure be polluted. It is obvious that the greater the number of people occupying a given area, the greater will be the amount of polluting substances in the water in or adjoining that area. The greatest amount of polluting waste must therefore be derived from large cities, and the rivers, lakes, or other bodies of water into which that waste is discharged must therefore carry the largest amount of foreign matter.

Two kinds of pollution may conveniently be distinguished, first, inorganic pollution, such as the acid waste from coal mines and steel mills, the lime from soap factories and soda pulp mills, and the dye

wastes from textile mills; second, organic wastes, such as the grain slop from distilleries, the wool scourings from woolen mills, the gums and resins extracted from wood in sulphite pulp mills, the drainage from stables, household wastes, and the bodily wastes of man. All of these wastes are objectionable, though in different degree. Inorganic wastes, unless they consist of mineral poisons, have no necessarily prejudicial effect on the health of those who use the water for drinking. Many of them, however, impart certain appearances to the water that render it objectionable for domestic use, for, as will be shown further on, one of the requisites of a good water supply is good appearance of the water. Many organic wastes are prejudicial to health, but if they occur in water in large proportions they render it so foul that its condition itself becomes a protection to the public, so far as its use for drinking is concerned. If they occur in proportion so small that their presence can not be detected by the person using the water they may or may not be dangerous. Whether dangerous or not, the idea of drinking such water is abhorrent and will not be tolerated in a civilized community. More important than all these considerations, however, is the fact that household and bodily wastes contain the germs of disease, and when these are discharged into water that s afterward used for drinking they reproduce their kind within the body of the drinker and thus widely disseminate disease.

The purification of water supplies therefore involves the removal of inorganic matter, the removal of organic matter, and the removal of the specific germs of disease.

Society is thus confronted by two necessities—first, the inevitable pollution of water resulting from man's occupation of the land; second, the necessity for a supply of pure water for drinking.

In this statement of conditions no mention has been made of organic pollution resulting from the natural growth in water of small vegetable and animal organisms, which impart color, odor, or taste, or all three, to the water. These further complicate the question.

People who live in towns and cities therefore have, as a result of their urgent necessities, a most important problem to solve—a problem which without suitable solution becomes progressively more and more difficult and urgent. Consideration will now be given to the various sources of public water supply and their liability to pollution.

SOURCES OF WATER SUPPLY.

SUPPLY OF CITIES IN THE UNITED STATES.

In the selection of a source of water supply two features are considered; first, a water must be satisfactory as to quality, and second, it must be available in sufficient quantity. In the Northern and

Middle Atlantic States the use of lake and spring water is common. The Great Lakes are sources of water supply for some of the largest cities in the United States, and the waters of smaller lakes are used abundantly by others. In the more southerly States waters from rivers are more commonly used, and in the upper Mississippi and the Ohio Valley districts ground waters are used to a considerable extent.

Statistics concerning municipal water supply[1] disclose some striking facts. In nearly 400 cities located in all parts of the United States and southern Canada, 40 per cent of the public water supplies are drawn from wells; 25 per cent from lakes, ponds, or springs; 24 per cent from rivers; and 11 per cent from mountain streams, impounded or otherwise. In 56 out of the 93 cities in the Ohio River valley and in 46 out of 85 cities in the upper Mississippi River valley water supplies are derived from wells. Of 131 cities in the New England and Middle Atlantic States, 56 take their supplies from lakes or springs; 28 from wells; 26 from mountain brooks; and 21 from rivers. The total volume of water taken from other sources is, of course, greatly in excess of that taken from wells.

GROUND WATERS.

If data could be obtained from all cities and towns in this country it appears certain that the majority would be found to take their water supplies from ground sources; that is, from wells, as distinguished from rivers, brooks, lakes, and other surface sources. Such wells are either sunk in gravelly soil or drilled in the rock, all of them extending into or through the water-bearing stratum.

Well waters, as a rule, are pure, clear, and colorless, although many are very hard and others contain much iron in solution. Such waters are not particularly objectionable for drinking, but hard waters are unsatisfactory for steam raising and many other industrial uses, and waters containing much iron are objectionable on account of the stains left upon fabrics washed in them. In many places means have been found to remove these objectionable constituents from the water.

The amount of water continuously available from wells is more uncertain than the amount of run-off from a given catchment area. In practically every part of the country a new problem is presented. If one well yields a daily minimum of 500,000 gallons it by no means follows that another well close by the first will double this yield. There is always a limit to the quantity of water which can be obtained constantly from a given area and it varies from place to place. Under the favorable conditions found on Long Island the yield from tubular wells is about 80,000,000 gallons daily. The catchment area

[1] Municipal Journal and Engineer, vol. 24, No. 19, May 6, 1908.

on which these wells are located is over 100 square miles in extent, and the yield is equivalent to about 750,000 gallons daily per square mile. This is the largest well supply in the country. Lowell, Mass., Camden, N. J., Meadville, Pa., Canton, Ohio, Memphis, Tenn., and San Antonio, Tex., are among the larger cities which now use well water, but the most extensive use is made of it by smaller cities, where the daily volume required is comparatively small.

The capacity of a given well supply obviously depends on the size of the catchment area from which the water is drawn, the precipitation which falls on this area, and the perviousness of the soil or underlying rock. When a well is pumped water is drawn from the sides as well as from the bottom. It follows, therefore, that by continued pumping the ground-water level will be lowered, but immediately around the well this level will be depressed in the shape of an inverted cone. In locating wells it is necessary to space them so far apart that the cones of depression do not intersect, for in the event that they do intersect the individual yield of each well will be reduced. Furthermore, it is necessary to locate the wells in a line across the direction of flow of the ground-water current, for if placed on a line in the direction of this current, the upper wells may draw the bulk of the flow.

There is no way of predicting what the yield of a well will be except by considering the yields of other wells in the same locality. Furthermore, the yield of a well depends to a certain extent on the facility with which water can enter it, and in many wells the flow has become greatly diminished or completely stopped by the clogging of the inlet openings.

LAKE SUPPLIES.

Chicago, Cleveland, Buffalo, Detroit, Erie, Duluth, and Milwaukee are among the larger cities which draw their water supplies from the Great Lakes, and millions of dollars have been spent in extending the intakes to points in the lakes where it is expected that pure water may be obtained. Along the shores of the lakes in the vicinity of cities the waters are of course badly polluted by the discharge of city sewage.

The Great Lakes receive the sewage of millions of people, and from them in turn millions draw their water supply. In most places these waters are consumed in their unpurified state. The danger should be obvious, but nevertheless these conditions continue to be common. The sewage of lake cities is usually discharged into the lakes near the shores. Considerations of cost often prevent the extension of sewer outlets far enough into the lakes to take full advantage of the diluting power of such bodies of water. The engineers in some cities located

on lake fronts have consequently made careful study of prevailing currents and winds for the purpose of locating the intakes of their waterworks at points unlikely to be reached by sewage. The ineffectiveness of such a safeguard is illustrated subsequently by citing the experience of Chicago and Cleveland.

When water is drawn from small lakes the possibilities of obtaining a pure supply are usually good. The purity of such supplies may be maintained by keeping all sewage out of the streams that feed the lakes and by enforcing strict sanitary measures on the drainage area. Rochester, N. Y., and St. Paul, Minn., are examples of cities still using lake water and maintaining it in a pure and wholesome condition. The fact remains, nevertheless, that all waters derived from surface sources require sharp and incessant watching, and even with such attention are liable to accidental pollution, which may result disastrously.

IMPOUNDED SUPPLIES.

Utility of impounding reservoirs.—Where the most suitable source of water supply is one or more comparatively small streams, it is frequently necessary to build impounding reservoirs in which to store the heavy spring and fall flow for use during the low periods of summer and winter. In this way use may be made of streams whose normal flow frequently falls below that necessary to supply the demand during certain seasons. Storage is also beneficial in other ways. It greatly minimizes the danger from such pathogenic pollution as the water may be subjected to before it reaches the reservoir, and it effects a substantial improvement in the physical quality of the water.

It is a well-established fact that sewage bacteria, and particularly the pathogenic organisms, die off rapidly in water. The pathogens die for numerous reasons, most important among them being unfavorable and unnatural surroundings, osmosis, an insufficient or unsuitable food supply, and the antagonistic influences of other bacteria and of some forms of animal life. Furthermore, bacteria do not persistently multiply in water, at least not under the climatic conditions of this country. It is a fact that although for a brief period there may be positive indications of bacterial propagation in standing water, this condition rapidly disappears and the bacteria show a rapid and steady diminution and in a few days or weeks may almost entirely disappear. The data already published on this point are abundant. For example, at Lawrence, Mass., the bacterial removal effected in the city reservoir, where the period of storage is about two weeks, amounts to over 93 per cent. At Washington, D. C., where the maximum period of storage is five or six days, the

bacterial removal is the same as at Lawrence. In the Boonton Reservoir, where the water supply of Jersey City is impounded, there is storage capacity for over 200 days' supply, and it has been found that during the time the water remains in the reservoir the average bacterial purification effected is 99 per cent.

The physical improvement in water resulting from storage consists of the subsidence of the fine suspended particles that give the water a turbid appearance and the reduction of color due to substances held in solution. The latter effect is produced in the main by the bleaching effect of the sun.

The foregoing comments are made in order to show the salutary effect of storage upon the quality of water. There are further important questions to be considered, however, such as the care which should be given to catchment areas above lakes and impounding reservoirs used for domestic purposes, and stagnation of lake and impounded water, which produces disagreeable tastes and odors in water.

Care of catchment areas above lakes and impounding reservoirs.— The most effective manner of preventing the pollution of an impounded water supply is to purchase the entire catchment area. This is rarely possible or feasible. It should also be emphasized that possession of the whole catchment area and the enforcement of sanitary regulations thereon does not preclude accidental or incidental pollution, such as might come from a chance trespasser suffering from a light case of typhoid fever or in the initial or convalescent stages of a severe case. Many watersheds well regulated and patrolled have been polluted in this way, causing such epidemics as those at Plymouth, Pa., in 1885; New Haven, Conn., in 1900; and Ithaca, N. Y., in 1903. Such epidemics show clearly how necessary and how impossible it is to always keep a vigilant eye on all sources of pollution in a drainage area.

The chief drawback to the acquirement of entire catchment areas usually is the cost. It is rare indeed that such cost will not far exceed that of a system of strict sanitary regulation over the area under the authority of suitable State laws combined with some form of purification of the water before it is supplied to the consumer. It is the usual and commendable custom, therefore, for those in charge, be they municipal officers or officials of a private company, to acquire the shores of the lake or impounding reservoir from which the water supply is drawn, and then to see to it not only that sewage or waste of otherwise dangerous character is not deposited in the reservoir or its affluent streams, but that it is not stored or deposited on any part of the catchment area from which it may at some time be washed into the reservoir. With such ownership and with an efficient system of sanitary patrol by diligent inspectors, it is possible properly to avoid

the great expense of purchasing the whole catchment area and to allow a rural population to remain undisturbed.

To recapitulate, it is always well to do all that can be done to keep the catchment area clean and to keep all sewage waste out of the water that enters the reservoir. Then, if the storage period is insufficient to allow the water to be satisfactorily clarified and decolorized, the water should be filtered before it is delivered to the consumers. If the water is physically satisfactory as it leaves the reservoir but still subject to sudden incidental or accidental pollution, sterilization is the cheapest and surest remedy.

Stagnation of impounded waters with particular reference to the production of objectionable tastes and odors.—It is well known that some waters, if not all, on being stored for long periods in lakes or impounding reservoirs, become stagnant. Such stagnation does not ordinarily occur throughout the body of the water in the reservoir but is particularly confined to the bottom layers, where, through the action of bacteria upon the deposits of organic matter, the oxygen in the water is entirely consumed, and foul tastes and odors are produced. A comprehensive report on this general subject by Hazen and Fuller was published in 1907, and to this the reader is referred.[1] Many attempts have been made in the past to overcome this undesirable feature in stored water. At perhaps a dozen places in Europe and this country, the top soil has been removed from the reservoir site before it was allowed to fill with water, the expectation being that the organic matter, which ultimately undergoes decay and produces stagnation, would be eliminated. Such stripping is always costly, ordinarily approaching probably $1,000 an acre of surface, and appears to have been of but temporary benefit wherever tried. In such reservoirs a deposition of organic matter from the water is always going on, and in time the conditions at the bottom will be quite as bad as though it had not been stripped. Hazen and Fuller recommended aeration and filtration to remove tastes and odors from stagnated water. It is desirable to point out, however, that in the majority of reservoirs odors and tastes due to stagnation are not as troublesome as those from certain forms of animal and vegetable life, commonly known as algæ. These tastes and odors are caused by the essential oils which those organisms secrete during their growth. For a thorough work on this subject the reader is referred to Whipple's "Microscopy of drinking water." Much practical benefit may be derived from the treatment of reservoir waters with copper sulphate during periods of trouble from growth of algæ. A good summary of the evidence bearing on the effectiveness of copper compounds in the destruction of algæ is contained in the Journal of the New England Waterworks Association, December, 1905, and in Bulletin No. 100, part 7,

[1] Rept. Board Water Supply New York, 1907, pp. 181–255.

Bureau of Plant Industry, United States Department of Agriculture, issued October 20, 1906.

Fortunately such troubles as may arise from the growth of algæ in reservoirs extend over comparatively short periods of time—that is, during the summer months of the year. Furthermore, with the judicious use of copper compounds such growths may be effectively and cheaply stopped. The growth of these algæ may not only of itself produce tastes and odors in water, but if they are allowed to grow undisturbed and to die naturally they add to the organic matter which brings about the stagnation of the lower strata of the water therein. By their elimination at the outset, therefore, a twofold good is effected.

RIVER SUPPLIES.

With the rapidly increasing population in the United States it is certain that in the future more and more use will be made of river waters as sources of public supply. It is also certain that the amount of polluting matter which practically all rivers of size in this country are obliged to carry is increasing year by year. This single fact requires the sanitary aspects of river-water supplies to be commented on at some length.

One of the first facts to be recognized in connection with the discharge of sewage into running water and the use of such water as a source of public supply is that no practical method of sewage purification will remove absolutely all danger from pathogenic germs. In the construction of a sewerage system, however complete and tight, provision must always be made for storm or emergency overflows. In "separate" sewerage systems, which are designed to collect all of the house wastes in one system of pipes and all of the street wash and much of the industrial waste in another system of pipes, it is necessary to provide emergency overflows at outlets or pumping stations, which become operative in the event of great inflows of storm water or the disarrangement of the pumping machinery, or of any part of the purification works if such works are provided.

In "combined" systems, which carry in the same pipes household and industrial wastes and street washings, storm overflows directly connected with the river are always built and become operative at times of heavy storms, when the capacity of the sewers becomes overtaxed. It is clear, therefore, that in any system of sewerage it is impossible to depend absolutely on all of the dangerous material being kept out of the river. In addition to this, sewage purification works, even when operated in the most careful manner, occasionally allow the escape of some material of a dangerous character.

It is therefore apparent that the primary object of a sewage disposal plant is merely to render as nearly inoffensive as possible the more

offensive parts of the sewage, and to purify it to the highest degree commensurate with the benefits to be derived under existing conditions. Public waterways must continue to receive the sewage of cities, and the one thing which remains to be done is to see that such wastes are made as unobjectionable as possible before their discharge. That is practically all that any community should be required to do.

The capacity of a stream to dispose of sewage without creating offense depends on the initial pollution of the stream, on its volume, and on its velocity of discharge. If the stream receiving the sewage is large enough and the time allowed for natural purification to take place is long enough, no nuisance will be created. In some parts of the country, however, so many cities are located on one stream, that the capacity, particularly during the warmer months of the year, is overtaxed, and the water of the stream becomes ill-smelling and unsightly. To ameliorate such obnoxious conditions, but more often to avoid litigation brought or threatened by riparian owners below, some cities have been forced to purify their sewage before discharging it into the stream, and, owing to the proximity of one city to another, all the cities have been driven to consider ways of obtaining a pure water supply from some other source or of purifying the badly contaminated water of the stream.

The ideal state of affairs, toward which American sanitarians are working, is to permit all cities to discharge their sewage into the nearest stream but to require them first to purify it to a degree which will preclude the establishment or maintenance of obnoxious conditions in the stream. Rarely are two problems of this kind found to be alike. The sewage of some cities should be purified to a far greater degree than that of others, dependent on the initial pollution of the stream, its minimum volume and velocity of discharge, and the distance to the next city, or, more exactly, to the intake of the next waterworks.

The partial purification of all the sewage entering a stream being effected, and the water of this stream being afterwards used for public supply, it becomes necessary finally to purify the stream water before it is delivered to the consumer. This it is always possible to do.

DEVELOPMENT OF WATERWORKS IN THE UNITED STATES.

Developments in public water supply in the United States have been rapid since 1850, although the first municipal works were built in Boston nearly 200 years before that date. Creditable progress has been made both in the number of works and improved equipment. In his "Manual of American waterworks" (1900) Baker

records in tabular form the development of waterworks in this country from 1850 to 1896, as follows:

Development of waterworks in the United States, 1850–1896.

Year.	Number of works.	Number of works built during the period.	Year.	Number of works.	Number of works built during the period.
1850	53	.....	1875	422	179
1855	106	53	1880	598	176
1860	136	30	1885	1,013	415
1865	162	26	1890	1,878	865
1870	243	81	1896	3,196	1,318

Commenting on these statistics, Turneaure and Russell in their work entitled "Public water supplies" (1901) state as a matter of record that the total population supplied in 1880 was 11,809,231, and that in 1890 it was 22, 814,061. The total estimated cost of the works up to 1891 was $543,000,000. H. M. Wilson in a paper on fire wastes[1] gives the total cost of waterworks systems in 1907 as $1,129,247,532. From available information it appears that about one-quarter of the communities having populations between 1,000 and 5,000 are provided with public waterworks, and that 90 per cent of the cities having populations between 5,000 and 25,000 are similarly provided. Comparatively few cities of over 25,000 inhabitants do not now have public supplies.

WATER CONSUMPTION.

The average American citizen is wantonly wasteful in the use of water. Statistics of water consumption show a great difference between the amount consumed by cities in Europe and in America. The average daily consumption in 17 large cities in England, Germany, and France is about 37 gallons per capita, the highest being about 66 gallons, at Glasgow, and the lowest about 20 gallons, at Nuremberg. The per capita consumption in the average American city is nearly four times as great. In New York City the daily per capita consumption is about 130 gallons; in Chicago, Philadelphia, and Pittsburgh it is close to 200 gallons.

The Municipal Journal and Engineer has gathered interesting statistics on this point from different parts of the country. These data are given in condensed form in the next table. The figures in the column showing water consumption were obtained by dividing the total gallons consumed by the total population of the cities, and not by the number of actual consumers, otherwise the per capita daily consumption shown would be considerably higher.

[1] Read at the convention of the American Waterworks Association held at Milwaukee in June, 1909.

Average per capita consumption of water in representative American cities.

Region.	Number of cities.	Daily consumption in gallons per capita.
New England	49	85
Middle Atlantic States	44	137
South Atlantic States	15	90
Ohio Valley	55	88
Upper Mississippi Valley	53	73
Lower Mississippi and Gulf region	6	53
Rocky Mountain region	5	283
Pacific coast	5	204
Canada	9	108
Total	241	[a] 100

[a] Weighted average.

The excess of the per capita consumption of water of America over Europe can be traced almost directly to the personal habits and financial status of the two peoples. Bathtubs are found in but few houses of people of the middle class in Europe and in no houses of people of the poorer classes. Water closets are rare and have much smaller flush tanks than in this country. The water waste occasioned by plumbing systems, an enormous waste in America, is cut to a minimum in Europe. The average European is habitually more economical than the average American and for many reasons endeavors to utilize to completeness all things which are necessary to existence. In Japan, where the water-closet is virtually unknown, and where the water of a bath is used by several people, one after another, and where, finally, there are no sewers except in small parts of the larger cities, the average consumption of water is even lower than in western Europe and amounts to about 25 gallons per capita daily. Although water for toilet use should not be stinted in amount, and although there is no disposition among the advocates of water economy to discourage habits of cleanliness, it is a fact, established beyond all disproof, that the present consumption is largely in excess of the amount necessary to secure the desired end. Consequently the use of water meters on house service has become very common, not, it should be emphasized, to reduce the necessary consumption, but to impart to the householder the habit of giving thought to needless waste.

The use of meters to prevent water waste is said to date back to the reign of the Emperor Claudius. Progress in meter use has been slow until very recent years. There has always existed in this country a prejudice against any restriction on the individual use of water. Many claims relative to the alleged disease-breeding qualities of water meters have been made, but all have been shown to be unfounded. Probably the most common and at any rate the most sincere objec-

tion to the use of meters advanced by those who are relatively uninformed on the subject is that the effort of persons in whose homes the water is metered to reduce as much as possible the charge for water service would result in diminished personal cleanliness, which might indirectly contribute to disease. There is no evidence that such an effect was ever produced, and a moment's consideration will show that such occurrence wou'd be most unlikely. The difference between personal cleanliness and personal uncleanliness is represented by a relatively small amount of water—so small, in fact, that the difference in water charges under a metered service would be almost negligible.

The Buffalo Chamber of Commerce published in its journal, The Live Wire, for February, 1911, some interesting results of an investigation of the use of water meters. Replies to a request for information regarding the advisability of installing water meters were received from 49 health officers and 60 superintendents of waterworks. These officials represented municipalities having populations of more than 50,000 people each and a total population of 16,000,000. Forty-two of the forty-nine health officers and fifty-eight of the sixty water-works superintendents were in favor of meters.

TYPHOID FEVER IN THE UNITED STATES.

DEATH RATE FROM TYPHOID FEVER.

Typhoid fever is the most common of all water-borne diseases in this country. The United States Census report for 1900 gave the total number of deaths from typhoid fever during that year as over 35,000. More recent information from the same source is now available and is brought together herein in tabular form. These data were largely compiled from reports of the Census Bureau, and are of more than usual accuracy for the reason that they were taken from the returns of such cities as have approximately complete registration of deaths, based upon the compulsory requirements of burial permits.

According to bulletins of the Bureau of the Census,[1] the total estimated population of the aggregate registration area was 45,028,767 in 1908, or nearly 52 per cent of the total estimated population of continental United States. The total number of deaths from typhoid fever for the entire registration area was 10,722 for 1909 (22 per 100,000 population), as against 12,670 for 1907, and 11,375 for 1908. The lowest death rates from this disease in 1908 were found at Worcester, Mass., 10.5; Jersey City, N. J., 9.7; and Paterson, N. J., 9.2. All the other large cities in this country had death rates from typhoid fever in 1908 exceeding 10 per 100,000 population.

[1] Mortality statistics for 1908: Bull. Bur. Census No. 104, 1909, pp. 7, 13. Mortality statistics for 1909: Bull. Bur. Census No. 108, 1910, pp. 7, 22.

In 1910 the average death rate from typhoid fever in the 48 cities in the United States having populations in excess of 100,000, and representing a total population of nearly 20,000,000, was 23.3 per 100,000 population. In the same cities the average death rate from typhoid fever for the five years ending with 1910 was 27.6 per 100,000 population. The lowest rates in 1910 per 100,000 population were 6 in Cincinnati, Ohio; 7 in Paterson, N. J.; 9 in Bridgeport, Conn.; and 10 in Jersey City, N. J.

Attention is drawn to the possibility of reducing the death rate from this disease even below 10 per 100,000, as shown in death rates from enteric (typhoid) fever taken from the statistics of Scottish, Irish, colonial, and foreign cities, in the Annual Summary for 1908, published by the registrar general of England and Wales. In this document the following low death rates are found: The Hague, 1; Stockholm, 1; Edinburgh, 2; Munich, 3; Berlin, 4; Hamburg, 4; Vienna, 4; Breslau, 5; London, 5; Rotterdam, 5; Dresden, 6; Copenhagen, 7; Glasgow, 8; and Paris, 8. Other foreign cities have higher death rates from this disease, but the list given by the registrar general discloses no cities with death rates from typhoid fever as high as the average of American registration cities (25.3) in a most favorable year (1908), except St. Petersburg, 126; Moscow, 56; Milan, 38; Montreal, 35; and Toronto, 28.

In the following table are presented statistics of the death rate from typhoid fever in some of the more important cities in this country. The 48 cities named in the table had a total population in 1910 of nearly 20,000,000.

Death rates from typhoid fever in cities of the United States with populations in 1910 of 100,000 or more.[a]

City.	Death rate from typhoid fever per 100,000 population.							
	1906	1907	1908	1909	1910	Average for 6 years 1900–1905, inclusive.	Average for 5 years 1906–1910, inclusive.	Average for 11 years 1900–1910, inclusive.
Albany, N.Y.	20	20	11	19	15	25	17	21
Allegheny, Pa.	136	97	40	28	47	107	70	90
Atlanta, Ga.	50	64	47	44	43	65	50	58
Baltimore, Md.	34	41	31	23	41	36	34	35
Birmingham, Ala.	39	71	64	44	51	50	54	52
Boston, Mass.	22	10	26	14	11	23	16	20
Bridgeport, Conn.	10	13	13	13	9	15	12	14
Buffalo, N. Y.	24	29	21	23	20	29	23	26
Cambridge, Mass.	18	10	10	9	12	18	12	15
Chicago, Ill.	18	18	15	12	14	27	16	22
Cincinnati, Ohio	71	46	19	13	6	54	31	44
Cleveland, Ohio.	20	19	13	12	19	51	17	36
Columbus, Ohio.	45	38	110	17	13	61	45	54
Dayton, Ohio.	28	38	16	24	18	29	25	27
Denver, Colo.	68	67	58	24	30	37	49	42

[a] Statistics gathered by correspondence and taken from Bull. Bur. Census Nos. 104, 1909, and 108, 1910.

Death rates from typhoid fever in cities of the United States with populations in 1910 of 100,000 or more—Continued.

City.	Death rate from typhoid fever per 100,000 population.							
	1906	1907	1908	1909	1910	Average for 6 years 1900–1905, inclusive.	Average for 5 years 1906–1910, inclusive.	Average for 11 years 1900–1910, inclusive.
Detroit, Mich	22	28	22	19	16	17	22	19
Fall River, Mass	8	18	13	14	15	19	14	17
Grand Rapids, Mich	39	30	30	17	27	34	28	31
Indianapolis, Ind	39	29	26	22	31	76	30	55
Jersey City, N. J	20	14	10	8	10	19	12	16
Kansas City, Mo	38	40	35	23	38	48	35	42
Los Angeles, Cal	18	23	19	18	12	35	18	27
Louisville, Ky	63	79	49	43	31	55	53	54
Lowell, Mass	7	9	24	11	21	19	14	17
Memphis, Tenn	39	35	33	41	28	37	35	36
Milwaukee, Wis	31	26	17	21	45	19	28	23
Minneapolis, Minn	33	26	18	20	58	38	29	34
Nashville, Tenn	66	85	62	53	48	54	58	56
Newark, N. J	18	24	12	11	13	17	16	17
New Haven, Conn	54	30	34	20	17	44	31	38
New York, N. Y	15	17	12	12	12	19	14	17
New Orleans, La	30	56	31	25	28	40	34	37
Oakland, Cal	26	28	18	7	13	19	18	19
Omaha, Nebr	28	24	22	31	75	20	36	27
Paterson, N. J	4	11	10	5	7	25	7	17
Philadelphia, Pa	74	60	36	22	17	47	42	45
Pittsburgh, Pa	141	135	[a] 53	[a] 13	[a] 12	132	71	104
Providence, R. I	19	8	16	12	18	20	15	18
Richmond, Va	44	41	50	24	22	66	36	53
Rochester, N. Y	17	16	12	9	13	15	13	14
St. Louis, Mo	18	16	15	15	14	33	16	25
St. Paul, Minn	21	17	12	20	20	14	18	16
San Francisco, Cal	.....	57	27	17	15	20	29	24
Scranton, Pa	11	76	11	11	14	18	35	26
Syracuse, N. Y	10	16	15	12	30	14	17	15
Toledo, Ohio	45	36	40	31	32	36	37	36
Washington, D. C	52	36	39	33	23	59	37	49
Worcester, Mass	12	14	10	8	16	17	12	15

[a] Filtered-water section. Allegheny district not included.

The foregoing table shows that the general tendency in these 48 large cities was in the direction of lower death rates from typhoid fever. During the period 1900–1905, inclusive, the average death rate from this disease in these cities was 37 per 100,000 population; in 1906 it was 36; in 1907, 36; in 1908, 27; in 1909, 20; and in 1910, 24. This consistent reduction in the typhoid death rate is significant, and if future years show as great improvement it will not be long before the cities of this country will be as free from this disease as the best European cities.

The reduced rates at Albany, Cincinnati, Columbus, Indianapolis, New Haven, New Orleans, Paterson, Philadelphia, Pittsburgh, and

Washington are undoubtedly due in a very large measure to the new water-filtration works at those places. The improved lake water supply at Cleveland was undoubtedly the cause of the marked fall in the typhoid death rate of that city, and the same was true of Chicago. Coagulation followed by sedimentation of the water supply proved beneficial at St. Louis, and the already low death rate in Jersey City underwent another reduction, due perhaps to the sterilization of the impounded but unfiltered water supply with hypochlorite of lime, which was begun in the autumn of 1908.

FINANCIAL ASPECTS OF IMPURE WATER SUPPLIES AND TYPHOID FEVER.

The number of cases of typhoid fever resulting directly from infection through polluted water supplies can not be precisely stated. Large European cities with the most carefully watched water supplies, such as Berlin, Hamburg, Vienna, and London, have annual typhoid death rates as low as 4 or 5 per 100,000 population. In this country, even in cities which have water supplies of acknowledged high standard, the death rate is two to five times as high as this. In Boston, Fall River, Jersey City, Newark, New York, and other cities the death rate from typhoid fever has for years been about 15 or 20 per 100,000, and this rate has come to be accepted by sanitarians in this country as strong indication of a pure water supply.

It has been shown repeatedly that the substitution of a pure for a polluted water supply results in a drop of about 75 per cent in the death rate from typhoid fever, accompanied by a material reduction in death rates from other intestinal diseases. The United States census reports give the total number of deaths from typhoid fever in the United States in the year 1900 as 35,000. With this figure as a basis, the computation shows that the introduction of pure water would save 26,000 lives annually. On the common assumption of $5,000 as the average money value of a human life, about $130,000,000 of vital capital is dissipated by typhoid fever each year. Again, to cause these 26,000 deaths not less than 260,000 people must have suffered from typhoid fever, as a conservative estimate of the mortality in this disease is about 10 per cent. If the average cost of a case of typhoid fever in the event of recovery, including lost time and charge for medical attendance, is taken at $300, a very low figure, $78,000,000 more is dissipated in this way, a total loss to the country of over $200,000,000 each year. Such figures as these have only a general significance, of course, but they serve to indicate what might be the result of a general improvement in the water supplies of this country.

The question of lost vital capital may be more specifically approached in another way. Between 1900 and 1905 the average typhoid death rate in the United States was about 50 per 100,000 population, but it is to be borne in mind that this high rate was in a large measure due to the prevalence of this disease in small villages and small isolated communities which would be difficult to reach in a widespread campaign for purer water. But in the larger cities of over 50,000 population the average typhoid death rate for the same period was about 35 per 100,000. This rate has been obtained by reviewing the statistics for the period 1900–1905, inclusive, in 74 cities having an aggregate population of 18,000,000. Only 24 of these cities had typhoid death rates of 20 or less per 100,000 population. Fifty cities, having an aggregate population of 11,000,000, had a typhoid death rate of 41 per 100,000. In other words, 4,510 people in these 50 cities died annually during the years 1900–1905 from typhoid fever. If it is correct to assume that for American conditions and manner of living, a death rate from typhoid fever as high as 20 indicates a satisfactory water supply, then each year 2,310 people were killed by impure water in these 50 cities. If a life is worth $5,000, then the deaths of these people caused a waste of $11,600,000 in vital capital. The total number of cases of fever required to destroy this number of people was over 20,000, and the cost of these cases, estimated at $300 each, adds $6,000,000 to the unnecessary waste. The total waste was therefore $17,600,000 each year for these 50 cities.

The cost of water filtration works for all of these 11,000,000 people, in order to save the lives of those sacrificed to impure drinking water would be about as follows: At 100 gallons per capita daily consumption, a total daily filtering capacity of 1,100,000,000 gallons would be required as a minimum. Although plants vary in cost, a fair average of the total cost of filtered water, exclusive of pumping charges but including all costs in connection with the operation of the filters, supplies, interest on the investment, and a reasonable sum for depreciation, is $10 per million gallons. The total cost of 1,100,000,000 gallons daily, therefore, would be $11,000 a day, or $4,015,000 a year. When this is compared with the $17,600,000 given above and the figures considered from every point of view, there is every argument in support of pure water to cut down the ravages of typhoid fever. Not the least of these is the financial aspect, as shown.

WATER SUPPLY OF CHICAGO.

Some interesting facts concerning the agency of polluted water in the occurrence of typhoid fever are shown by the experience of Chicago, Ill., and Cleveland, Ohio, which, as already stated, take their supplies from the Great Lakes.

The city of Chicago is located on Lake Michigan and has always drawn its water supply from that lake. Up to 1901 all of the sewage of the city was discharged at points along the entire water front. Chicago River, which was then a most foully polluted stream, also discharged into the lake about midway or a little to the north of the middle of the city's water front.

The water supply was drawn from several "cribs," located from 1½ to 4 miles from the shore, and it was the custom to keep the water about these cribs under close observation from day to day. When it appeared that winds or currents were carrying the sewage toward the crib from which the supply was then being drawn a shift was made to some other crib not then so affected. It is clear that such a plan must have resulted in polluted water being supplied to the city at times, for there was no way of positively detecting contamination until the mischief had been done, and for years the city paid a heavy toll to typhoid fever. In the early nineties it was common for 1,500 people, or 90 per 100,000 population, to die of this disease in Chicago every year.

To ameliorate this highly unsatisfactory state of affairs the Chicago Drainage Canal was built. The object was to divert the sewage of the city from the lake into Chicago and Desplaines Rivers. The canal was put into service in 1901 and at the present time the bulk of the sewage of Chicago is cared for by it. A marked decrease in typhoid fever in the city has resulted. A more or less indefinite portion of sewage still enters the lake, and the city is still liable to epidemics from typhoid fever in consequence of this. It is also true that a limited opportunity for pollution is caused by boats which traverse the lake in the vicinity of the water cribs. At this date the question of purification of the city water supply is being agitated to some extent. There seems to be little doubt that further treatment of the water is necessary to free the city from danger from this source.

WATER SUPPLY OF CLEVELAND.

The city of Cleveland takes its water supply from Lake Erie, and has always been troubled with an abnormal amount of typhoid fever, much of it due to the contaminated condition of the water supply. The sewage of the city is discharged into the lake along the water front.

The old intake was located about 1¼ miles from the shore of the lake and was used up to 1904, when a new intake, 4 miles from the shore, was substituted for the old. The improvement was almost immediately apparent and was made the more so by the fact that the city was in the grasp of a particularly severe typhoid epidemic at the time the new waterworks were put into service. In his book on

typhoid fever (p. 171) Whipple has shown the improvement effected by the introduction of the new supply, as follows:

Average number of new cases of typhoid fever reported daily in Cleveland, Ohio, in 1904.

Jan. 1–31, 1904: Period prior to the epidemic caused by flood	2.84
Feb. 1 to Mar. 5: Period of epidemic corresponding to exclusive use of old supply	20.91
Mar. 6–15: Period of epidemic corresponding to use of one-half of supply from new intake and one-half from old intake	11.10
Mar. 16 to Apr. 21: Period of epidemic corresponding to use of three-quarters of supply from new intake	2.89
Apr. 22 to Dec. 31: Period corresponding to exclusive use of water from new intake	1.03

The new supply (1911) is a very material improvement over the old, but there is no doubt that further treatment of the lake water is necessary before the city will be assured of a supply constantly pure and wholesome in character and not subject to occasional contamination.

The typhoid epidemic of 1910 at Milwaukee, Wis., and of 1911 at Erie, Pa., are proof enough of the danger in using the waters of the Great Lakes without purification of some sort. This danger must soon become generally recognized. It is not improbable that simple sterilization of the waters, which are ordinarily satisfactory physically, may be the next step taken in the direction of a safe water supply for many lake cities.

WATER PURIFICATION.

HISTORICAL SKETCH.

The ruins of antiquity show that large storage reservoirs were common in ancient times, and it is well known that the Chinese for thousands of years have used alum as a coagulant in muddy water in order to accelerate clarification. Perhaps the earliest literary reference to filtration appears in the "Ousruta Sanghita," a collection of medical lore written in Sanskrit probably 4,000 years ago. In a letter to the British Journal of Preventive Medicine, Mr. Francis E. Place, of Jaipur, Rajputana, India, calls attention to this reference, in which the following statement appears: "It is good to keep water in copper vessels, to expose it to sunlight, and to filter it through charcoal."

Modern history does not record any attempt at filtration until 1829, when the 1-acre slow sand filter was built by James Simpson for the East Chelsea Water Co., at London, England. The germ theory of disease was then unknown, and the filter was built to perform the offices of a mechanical strainer for the purpose of removing the turbidity from the water. This filter is still in service, however, and is

doing work of a nature far exceeding the purpose for which it was designed and built.

Typhoid fever as a specific disease was discovered in 1829, but it was not until 1849 that the germ theory of disease was seriously advanced. An act of the British Parliament of 1852 made compulsory the filtration of the entire water supply of the metropolitan district. This action was the result of the severe cholera epidemic of 1849 and was the first of a series of attempts to purify water for hygienic reasons.

The first noteworthy movement in this country for the purification of a public water supply was made in 1866, when the city of St. Louis sent James P. Kirkwood to Europe with instructions to investigate the art of the purification of water as there practiced. On his return Mr. Kirkwood made an elaborate report, which will always remain one of the classics on the subject. His recommendations for St. Louis were not adopted, however, apparently for sound reasons, as none of the purification works in Europe which came under Mr. Kirkwood's observation had a water to treat that was similar to the water at St. Louis. The waters of western Europe are almost uniformly clear, whereas that of the Mississippi is extremely turbid.

In 1872, about five years before Mr. Kirkwood's death, a plant was built at Poughkeepsie, N. Y., in accordance with his plans. This was the first practical attempt at purification of a municipal water supply in America. Plants of a type similar to that built at Poughkeepsie were built somewhat later at Lowell, Mass., Columbus and Toledo, Ohio, and elsewhere, but most of them failed of the purpose for which they were intended.

Quite extensive experiments on slow sand filtration were also made at Boston, Mass., Louisville, Ky., and elsewhere.

The classic investigations of the Massachusetts State Board of Health at Lawrence, Mass., were begun in 1887 and are still in progress. Up to a few years ago the work at the Lawrence Experiment Station, so far as water purification is concerned, was limited to studies on slow sand filtration. The construction of the Lawrence city filter, first placed in operation in 1893, was one of the results of these investigations.

In 1893 the first carefully conducted experiments with the newer process of mechanical water purification were made by Edmund B. Weston on the water supply of Providence, R. I., and in 1895 the much more elaborate studies in the same line were begun at Louisville, Ky., and continued through 1897. These Louisville experiments, conducted under the direction of George W. Fuller, formed the beginning of practical demonstrative investigations into the various methods of water purification. Similar studies followed successively

at Pittsburgh, Pa.; Cincinnati, Ohio; Washington, D. C.; New Orleans, La.; Philadelphia, Pa.; and elsewhere.

All of this experimental work gave a great impetus to water purification in this country, and not only has the number of cities installing water-purification works increased rapidly during the last 10 years but the design and construction of such works has now reached a high plane of excellence. The more advanced ideas in this regard were first manifested in the works at Albany, N. Y., designed by Allen Hazen, and in the works of the East Jersey Water Co., designed by George W. Fuller and built at Little Falls, N. J. The former plant was first used in 1899 and the latter in 1902. At Albany the filters are of the slow sand type, and at Little Falls of the mechanical or rapid sand type.

In 1900, according to Hazen, 1,860,000 people, or 6.3 per cent of the urban population of the United States were being supplied with filtered water. In 1904 the number of people so supplied had increased to 3,160,000, or 9.7 per cent of the urban population of the country. Since that time many large cities have installed filter plants until now (1911) about 8,000,000 people, or over 20 per cent of the urban population, are being served with filtered water.

KINDS OF FILTRATION.

Considerable confusion has arisen as to the proper nomenclature for different types of filters for municipal water supplies, particularly as regards the older type, which originated in England, and the newer type, which was first applied in the United States. There are other kinds of filtration processes, but they are either modifications of the established and approved types mentioned, or else they have been shown to be of limited applicability in the treatment of public water supplies on a large scale.

The first type of filter, built at Chelsea, England, has been variously styled the "English," the "slow sand," or the "sand" filter; and the newer type, also originating in England but first applied and developed in the United States, has been called the "American," the "mechanical," the "rapid," or "rapid sand" filter. The essential differences in the two types of filters are as follows: In the English or slow sand filter a coagulating chemical is seldom used in preparing the water for filtration; the sand grains comprising the filter proper are small in size; the rate at which water is allowed to pass through the filters is slow; and in cleaning the beds a thin surface layer is removed from the bed, washed, and returned. In the American or rapid sand filter a coagulating chemical is always used in preparing the water for filtration; the sand grains of the filter bed are much coarser and more uniform in size than in the slow sand filter; the rate of filtration is

approximately 40 times that used in the slow filter; and the filter bed, when dirty, is cleaned in the filter itself by mechanical means. After all, however, the distinguishing difference between the two filters is the rate of filtration. They are both of English origin, and they are both sand filters. It would seem, therefore, that they would be sufficiently distinguished from each other if they are called "slow sand filters" and "rapid sand filters," and these names will be used throughout this paper.

The waters of the United States present a wide variety of conditions. The waters of the New England States are normally clear; those of the Central States are often highly charged with suspended matter. Many waters are clear but highly colored with vegetable stain. Others are both colored and turbid. In some the turbidity is caused by particles of clay of microscopic fineness; in others, as in the Missouri River water, the suspended mud is for the most part very coarse. Every water seems to possess peculiar characteristics, and even these characteristics are subject to wide variation.

As late as 12 years ago the opinion was generally held that one or another system of filtration was applicable to the satisfactory solution of all water-purification problems. More particularly did opinion lean toward the older and therefore better-established slow sand filter, as used with success in many places in Europe and in a few places in America. Careful experimentation with different systems of filtration, carried on at Louisville, Ky.; Pittsburgh, Pa.; Cincinnati, Ohio; Washington, D. C.; and elsewhere, demonstrated 10 years ago that the slow sand filter, which had proved successful in the treatment of European waters and the practically clear waters of the northeastern United States, was not strictly applicable in the treatment of very turbid waters—that is, waters carrying in suspension large quantities of mud. The chief difficulties to overcome were the physical imperfections of the raw water. These refer particularly to the mud contained in the waters of the South and the Central West. In the experimental work it was definitely shown at Louisville and Cincinnati that, owing chiefly to the muddy character of the Ohio River water, the newer process of rapid sand filtration would accomplish the required result more efficiently and economically than would slow sand filtration, and plants of the former type have been built and are now in successful operation in both those cities.

PREPARATORY TREATMENT OF WATER FOR FILTRATION.

Waters which in their raw state are normally clear and colorless practically require no preparatory treatment before filtration. Waters which are comparatively clear but highly stained by decaying vegetation, and which require treatment for the removal of bacteria,

may also be purified satisfactorily by slow sand filtration. This treatment, however, will remove only a relatively small part of the coloring matter dissolved in the water, and if it is desired to remove all of this color a coagulating chemical must be used. By coagulation the stains are thrown out of solution and are easily removed in a coagulated state by sedimentation and filtration. Under these conditions it is usually more economical to make use of the rapid sand filter as the final step in the purification process, for unless prefiltration is employed or a long period of settling follows the addition of a coagulant to the raw water, much of the coagulant will be deposited on the slow sand filter and the surface will speedily be clogged. Frequent and expensive scraping of the filter is necessary under such circumstances. The waters of the Missouri, the Mississippi, and the lower Ohio basins contain suspended materials largely mineral in character but varying greatly in the size of the particles. Some particles are comparatively coarse and settle out readily when the water is allowed to stand; others are of exceeding fineness, many of them less than 0.00001 inch in average diameter, which is smaller than the ordinary bacterium. Such turbid waters when applied to filters without preliminary treatment can not be satisfactorily purified.

It is in the purification of these muddy waters that the engineer finds some of his most difficult problems. The turbidity of the raw water shows abrupt changes from comparative clearness following long periods of drought, when the suspended matter it contains may be less than 50 parts per million (422 pounds to the million gallons) to great muddiness during freshets, when the suspended matter may amount to 2,000 or more parts per million (17,000 pounds to the million gallons). These changes from comparatively clear to very muddy water occur very suddenly, and the character of the suspended particles is subject to great variation. To remove the bulk of this suspended matter prior to filtration and to do it economically is no simple problem. If it is done by plain sedimentation, then the basins in which subsidence takes place must be large enough to deal satisfactorily with the water when in its worst condition (Pl. IV, p.42). If sedimentation is to be aided by preliminary coagulation, then the basins must be made large enough to permit adequate subsidence of the bulk of the coagulated matters before the water reaches the filters (Pl. VI, p. 48). With some waters several days' plain subsidence are required. Where coagulants are used, this period may be reduced to several hours.

In some places, as at Albany, N. Y., coarse "roughing" filters have been installed for the purpose of clarifying the water before filtration. Filters of a somewhat similar type treat the water at Philadelphia, Pa., before it goes to the final filters. At Wilmington, Del., the water is prepared for filtration by being first passed through

layers of broken stone and sponge clippings. In none of these places is a coagulating chemical made use of.

The old practice of clarifying muddy water by coagulation with compounds of aluminum, following this with a period of subsidence, probably originated in China thousands of years ago. For many centuries it has been the practice in that country to treat tubs of turbid water with alum by inserting a crystal of the chemical in the split end of a stick and then moving the crystal up and down through the water until enough is dissolved to effect a satisfactory coagulation. Where aluminum sulphate is used it reacts with the carbonates in the water and a practically insoluble precipitate of aluminum hydroxide, a magma of flocculent appearance, results. As coagulation goes forward the particles of mud and silt are drawn together in comparatively large aggregates and afterwards subside with considerable celerity. Many of the bacteria in the water also become entangled in the coagula and are likewise removed by subsidence.

Slow sand filters are seldom installed where waters of high turbidity are to be purified, although at Albany, Pittsburgh, Philadelphia, and Washington filters of this type are called on every year to treat waters which contain large quantities of sediment. At Albany the works as originally built provided for a period of plain sedimentation of about eight hours, but later a battery of coarse roughing filters was added to relieve the occasional heavy load on the filters. At the Torresdale works in Philadelphia no provision is made for preliminary sedimentation. Here preliminary filters of the rapid sand type, but in connection with which no coagulant is used, effect a substantial removal of suspended matter from the raw water before it reaches the slow sand filters. The Philadelphia works at Upper and Lower Roxboro and at Belmont include apparatus for plain sedimentation and prefiltration through various kinds of coarse material before the water goes to the final filters. At Pittsburgh there are no prefilters, but the raw water is clarified during a period of preliminary sedimentation of about one day (Pl. IV, p. 42). At none of these places is use made of a coagulating chemical at any stage of the process.[1]

At Washington, D. C., where the filters are also of the slow sand type, it was recommended by the expert commission, Messrs. Hering, Fuller, and Hazen, that a coagulant be applied to the unfiltered water during the very muddy periods. This recommendation was not followed in the works as originally laid out and built. A preliminary period of plain sedimentation is provided in three reservoirs, two old and one new, the combined time allowed for sedimentation being between three and six days. There are no prefilters in these

[1] These statements apply to conditions existing in June, 1911.

works, but provision is being made for the application of a coagulant to the water before filtration.

It has frequently been contended that the use of coagulants, such as ferrous sulphate or aluminum sulphate, may be deleterious to the health of persons who drink the water. Such a contention is not valid, and may best be refuted by pointing out the fact that no such deleterious effects have ever been observed among the millions of people in this country who have for years been drinking water treated with coagulants.

The prejudice against coagulants has, however, led to the adoption of slow sand filters, suitably equipped for coagulant use in times of high turbidity. There are reasons both for and against such a plan, the details of which will not be discussed here. Let it merely be said that the use of coagulants in conjunction with slow sand filtration has never been regarded with much favor in this country. In some places where the conditions are particularly favorable coagulants have been successfully used. At Indianapolis, Ind., for instance, the water has been treated with coagulating chemicals for the last five years or more. After adding the chemicals the water is allowed a period of 24 to 48 hours for subsidence. The results have been generally satisfactory. At Tokyo, Japan, potash alum is used during periods of muddy water, and the water so treated is allowed 36 hours for coagulation and subsidence before it is applied to the slow sand filter. From the officials in charge of these works in 1906 the writer was unable to elicit any but the most favorable reports regarding the use of chemicals under these circumstances. At Calcutta, India, alumino-ferric is successfully used during the rainy season of the year, namely, July, August, and September. After being treated with this chemical the water is allowed to flow into large settling basins, which are worked on the fill-and-draw plan but in which the average period of sedimentation can not be less than three or four days. After this sedimentation the clarified water is applied to slow sand filters. Alumino-ferric has also been used in small slow sand filter plants in Europe.

Double filtration is to-day practiced abroad in Altona, Bremen, Schiedam, Zurich, and Singapore. At Altona it is not of much benefit and its usefulness at Schiedam is debatable. At Singapore it is used chiefly to effect the removal of tastes and odors from the water, but has not proved particularly efficient. In slow sand filters the turbid raw water, if only for reasons of economy and whether coagulants are used or not, must first be passed through preliminary filters or be subjected to comparatively long periods of sedimentation. In rapid sand filters, whether the raw water is turbid, colored, or clear, it is always necessary to make use of a coagulating chemical. The

reason for this is that the sand grains in such filters are larger than those in the slow sand filter and the rate of filtration is much higher. Consequently it is necessary that the water as it flows to the filter should be thoroughly coagulated; that is, that the suspended matter, and the color if any is present, should be coagulated into aggregates of considerable size and that practically no suspended matter or color be present at such time in its natural finely divided or semi-soluble state. It is further necessary, in order to obtain the highest efficiency commensurate with economy in the operation of a rapid sand filter, that during and after coagulation the water be allowed a suitable period for the subsidence of the bulk of the suspended matter. The suspended matter which is left in this process, however, is or should be flocculent in character and not granular and finely divided, as it is where subsidence is unaided by coagulation. With such preparatory treatment of the raw water the cost of operating the filters should be reduced to the lowest practicable minimum.

SLOW SAND FILTRATION.

GENERAL DESCRIPTION.

A slow sand filter consists of a water-tight basin, usually 1 acre or less in extent, supplied with suitable underdrains and filled to a certain depth with stone, gravel, and sand. The floor and walls are of brick, stone masonry, or concrete, and in northern latitudes it is necessary, in order to get the best results, to roof the filter over to prevent it from freezing. Such roofs or covers are usually made up of a series of concrete groined arches, as shown in Plate I.

Along the bottom of the basin, as shown in Plate I, *A*, is placed a main drain, and leading into this from both sides and at regular intervals are lateral drains. The floor is covered with graded stone, as shown in Plate II, *A*, sufficiently deep to cover the lateral drains, and over this is placed a layer of fine gravel, as shown in Plate I, *B*. All this material is merely a part of the underdrain and takes no part in the water purification process. Above the gravel fine sand is laid smooth to a depth of about 3 to 4 feet (Pl. II, *B*). This sand is the real filtering material; that is, it is the sand, together with the gelatinous film formed at the surface of the sand by organic matter and sediment from the water, which gives the filter its efficiency as a water purifier.

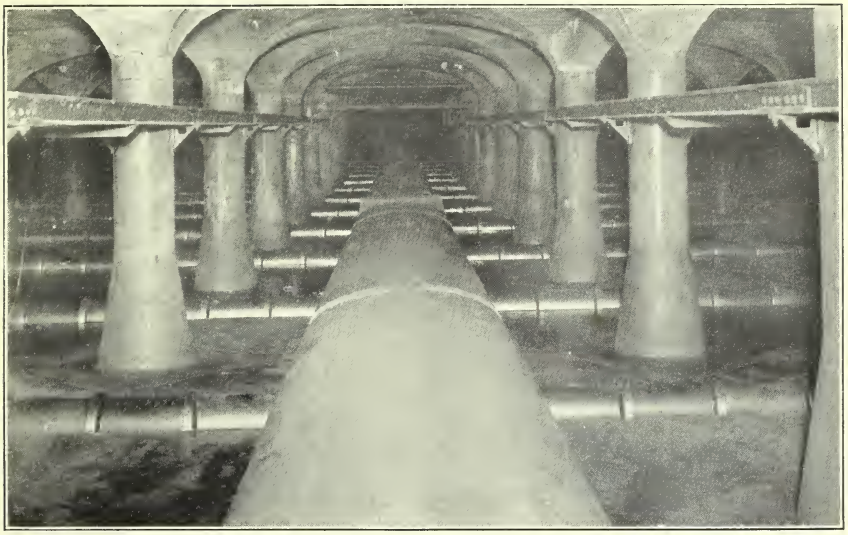
When the filter is ready for service the water is permitted to flow into it to a depth of about 3 feet and is allowed to percolate through these beds at a rate of about 75 gallons a day on 1 square foot of filter surface. This rate corresponds to a yield of about 3,000,000 gallons daily to the acre of filter surface. When a new filter is put into service it does not at once do its best work, but after a few

weeks' operation the sand grains throughout the bed become coated with an organic film and a slimy sediment collects on the surface of the sand layer. The filter is then most efficient. After a time its surface becomes so badly clogged that it is impossible to maintain a rate of filtration sufficiently high to be economical, and then the filter is shut down and allowed to drain, after which a thin layer of the top surface of the sand, from one-half to 1 inch in thickness, is scraped off (Pl. II, *B*). The filter is then refilled and filtration resumed, the water being first passed through at a low rate, which is gradually increased until the desired rate is obtained. On the basis that one such filter purifies 3,000,000 gallons each day, it is merely necessary to build a sufficiently large number of units to supply the amount required at any given place, but it is also necessary to install a sufficient number of extra units to take the place of those which are temporarily out of service and being cleaned.

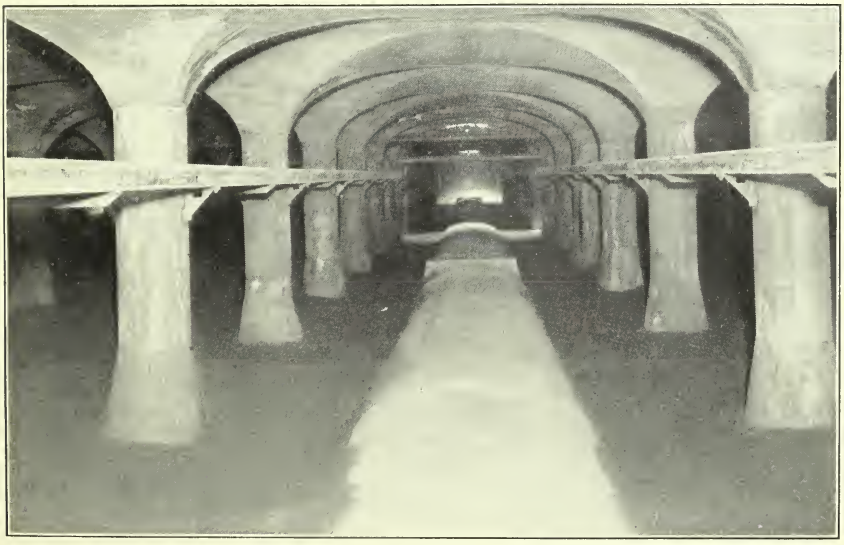
UNIFORM RATES OF FILTRATION NECESSARY.

Experience has shown that if a slow sand filter is efficiently operated the speed at which the water passes through the sand, or, as it is usually designated, the rate of filtration, must be uniform over all parts of the filter. It was formerly the belief that a slow rate of filtration would give a greater certainty of removing the foreign ingredients in the water than a rapid rate of filtration. It has been found, however, as explained further on, that very high rates of filtration can be maintained so long as the gelatinous film on the surface of the sand is not broken and if methods are used by which the filter can be cleaned more frequently at a low cost. The maximum rate at which filtration can be maintained varies with the condition of the water, the fineness of the sand, and certain other factors, but within reasonable limits the rate of filtration is controlled by the method and cost of cleaning the filter. Many slow sand filters in the country afford an inferior effluent on account of bad management and inadequate filter capacity. They are operated primarily to meet a demand for a certain quantity of water. Quality of effluent seems at these filters to be a secondary consideration.

A moment's consideration will show that a uniform rate of filtration must be maintained over the entire surface of the filter. If the rate be suddenly increased the fragile gelatinous film at the surface will be broken and at the immediately surrounding points the rate of filtration will increase sharply to the detriment of the quality of the effluent. If by such sharp increase in the rate even a small part of a filter bed is disturbed, the water passing through that part is imperfectly purified, and even though all the remainder of the filter is doing excellent work, there passes into the effluent this inferior



A. MAIN COLLECTOR AND LATERALS BEFORE SAND AND GRAVEL WERE PUT IN.

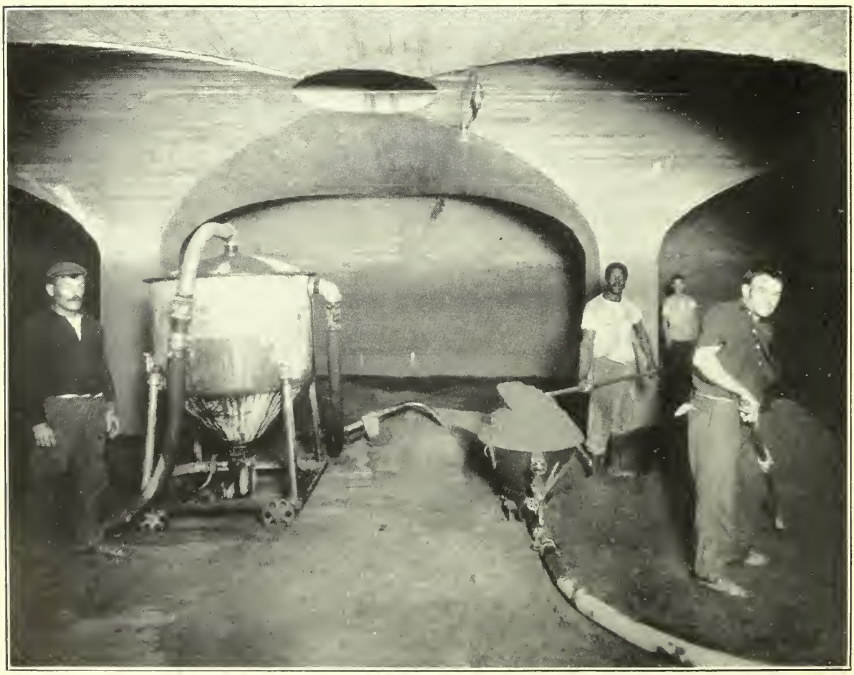


B. MAIN COLLECTOR AND LATERALS, WITH GRAVEL IN PLACE.

THE PITTSBURGH FILTRATION PLANT.

Photographs furnished by Bureau of Filtration, Pittsburgh, Pa.

A. QUEEN LANE PLANT, WITH COARSE GRAVEL IN PLACE.



B. TORRESDALE PLANT, SHOWING METHOD OF CLEANING WITH NICHOLS SEPARATOR.

PHILADELPHIA FILTRATION PLANTS.

Photographs furnished by Department of Public Works, Philadelphia, Pa.

water, which perhaps contains the germs of typhoid fever. This disturbance of the filter surface is further undesirable in that the continued operation of a filter which has suffered such disturbance will cause the penetration of mud and other suspended ingredients into the sand layer, the penetration taking the form of an inverted cone if the break is merely a puncture, or of a wedge if the break takes the form of a crack. When the filter is scraped or cleaned it is impracticable to remove all of this clogged portion, and it follows that at those particular parts of the bed the filter will remain virtually inoperative and the remainder of the bed will be forced to do correspondingly more work. On the other hand, if the rate of filtration in a slow sand filter is suddenly diminished to a marked extent there is a likelihood, particularly in the wintertime, of entrained air being released from the sand layer due to the abruptly diminished pressure in the filter. The release of air in this way may be violent and the filter bed and surface film badly broken in places. The consequences of such breaks, if the filter is continued in operation, are quite as serious and annoying as those caused by abruptly increasing the rate.

In most of the recent slow sand filter plants the rate of filtration is largely under automatic control through special devices, but in many filters of this type the rate is adjusted at more or less indefinite ntervals by filter attendants.

SAND HANDLING.

One of the most expensive features of the operation of a slow sand filter plant is that of sand handling. It is necessary to scrape the surface of the average slow sand filter about once a month, and the sand removed is either stored until a sufficiently large quantity is obtained for washing or else it is washed and replaced at each scraping. It is rarely more economical to throw away the sand scraped from the beds and make up the deficiency with entirely new sand than to wash such sand and replace it in a clean condition. The sand itself is usually expensive. When first procured it must be washed free from clay and screened before it is ready to be placed in the filter tank. Under favorable conditions in this country sand may be secured at $1.50 to $2.50 a cubic yard. Under very favorable circumstances such as obtained at Albany, N. Y., during the construction of the filters at that place, the sand cost about $1 a cubic yard; at Washington, D. C., in 1904, it cost $2.65 a cubic yard. The sand for the filters at Yokohama, Japan, cost $2.75 a cubic yard in 1906, a very high figure for sand in that country where labor is so cheap, but this cost resulted from the fact that the sand had to be transported a long distance uphill to the filter plant from the shores of Mississippi Bay, where it was dredged. At Osaka, Japan, the sand

is dredged from the bed of Yodo River immediately opposite the waterworks, brought to the shore in scows, spread out on the beach, sun dried, and afterward pan screened by coolies, who receive from 1 to 2 cents an hour for their labor. The cost of the sand in place at Osaka is about $0.65 per cubic yard, a figure so low that no attempt is made to recover by washing the sand scraped from the filters, and it is used for fill. So far as the writer knows, however, this is the only place where washing and replacing the sand scraped from filters is dispensed with.

The cost for labor in removing sand from a filter and washing and replacing it has thus far averaged around $1.50 a cubic yard. George W. Fuller gives some instructive figures gathered from some of the older plants on this point, as follows: [1]

Cost per cubic yard of handling sand in older filters and date filter was placed in service.

Lawrence, Mass. (1893)	$1.70
Mount Vernon, N. Y. (1894)	1.51
Albany, N. Y. (1899)	1.38

Another method of cleaning a slow sand filter is known as the "Brooklyn" method and was first used in 1905 by the New York City Department of Water Supply, Gas, and Electricity, at the suggestion of V. C. Brower, superintendent of the Hempstead filter plant at Rockville Center, Long Island. This method has been continued in use at several of the city filter plants on Long Island up to the present time, with very satisfactory results, both as to bacterial efficiency and as to freedom from subsurface clogging. The method consists in lowering the water to 1 inch in depth above the surface of the sand on the filter. Unfiltered water, generally taken from an adjacent filter in service, is then run in a stream over the surface of the sand to the outlet drain, a depth of about 1 inch of flowing water being maintained over the section to be cleaned. Men in rubber boots agitate the surface of the sand with long-toothed garden rakes, thus stirring the dirt from the sand and having it carried away to the drain. In order to secure the necessary velocity of flow with moderate quantities of water on a filter having large sand areas, the bed is cleaned in sections, the section undergoing cleaning being temporarily cut off from the rest of the bed by boards set on edge and driven down into the sand, forming a sort of flume with board sides and having a width of about 10 or 12 feet. After cleaning one section the boards are removed to a new position. When the dirt is removed the drain is closed, the filter is filled to its normal height with raw water, and filtration is resumed. William B. Fuller, who first tested this method experimentally, states that it requires

[1] Trans. Am. Soc. Civil Eng., vol. 46, 1901, p. 336.

about 1 per cent of wash water under the conditions of the New York City supplies, that the bacterial efficiency of filters so cleaned is apparently as high as that of filters cleaned by other methods, and that there is no subsurface clogging noticeable in five years' use of this method at Hempstead. This method has also been used by the city of Philadelphia at the Torresdale plant with successful results.

Fred C. Dunlap, chief engineer, Philadelphia Bureau of Water, states that 14 men and a foreman clean a three-quarter acre bed in eight hours, and that such a bed averages 19 hours a month out of service, including all elapsed time for draining, washing, and refilling.

More recent information of this point from large plants has been made available at Philadelphia, Washington, and Pittsburgh. At Washington, the dirty sand after being scraped is shoveled into portable ejectors (see Pl. II, *B*, p. 33, smaller device near center of picture) on the beds, to be thence forced by water pressure through pipes to stationary sand washers. After being washed the sand is discharged into concrete storage bins, from which carts, driven underneath, may be loaded. Until April, 1909, the washed sand was replaced in the filters by carts, which took the sand over the top of the filter and dropped it through manholes on revolving chutes for distribution over the filters. The total cost of sand handling is given by Hazen and Hardy [1] as $0.42 per cubic yard, this total being made up as follows:

Cost per cubic yard of sand handling at Washington, D. C.

Scraping (5 cents) and leveling (3 cents)	$0.08
Ejecting	.14
Washing	.04
Storing and replacing	.16
	.42

Since April, 1909, the washed sand has been restored to the filters by a hydraulic method in which an ejector is placed under the sand storage bin and the sand then ejected through pipes and hose to the filter. This method is considerably more economical than the old method and gives satisfactory results.

MACHINES FOR SAND WASHING.

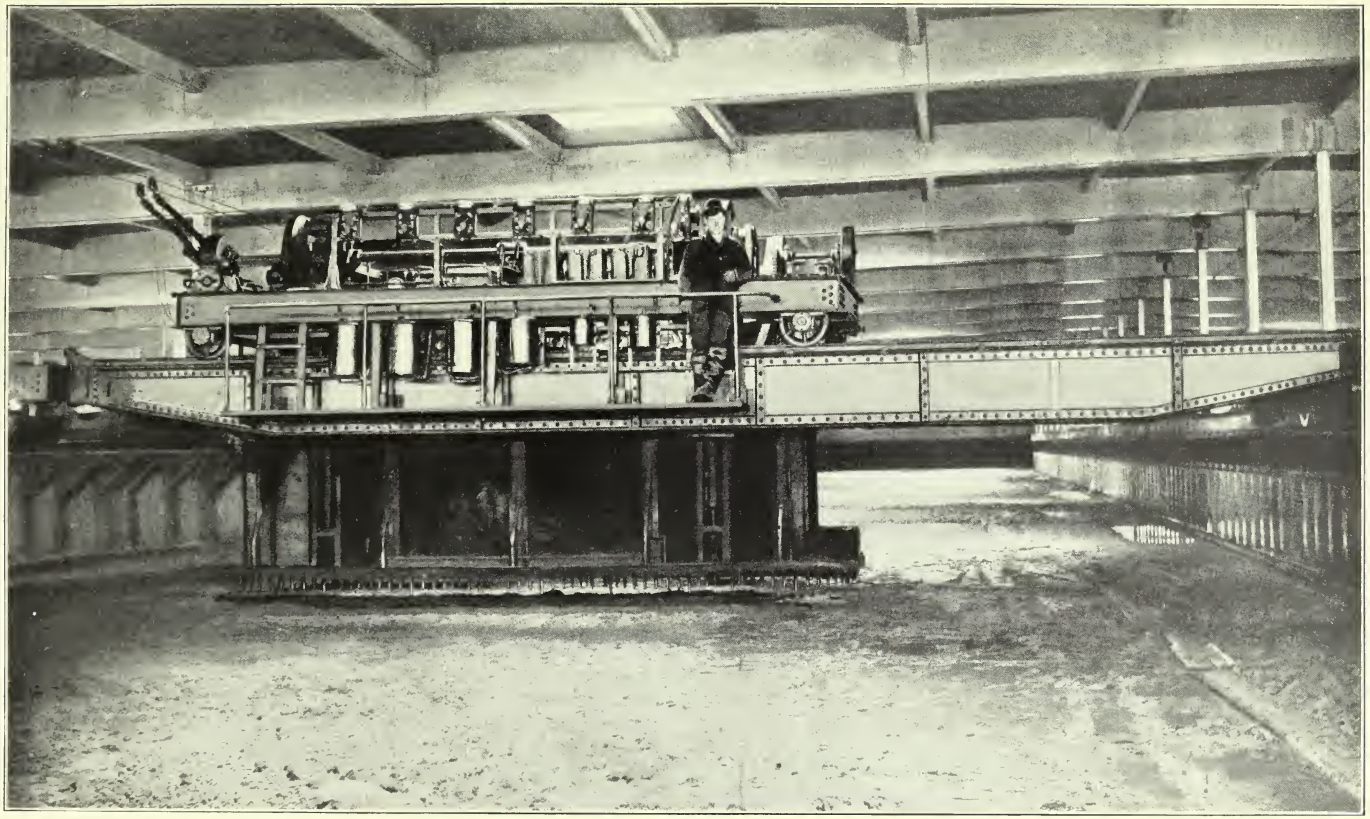
An improved apparatus for sand cleaning was given a thorough trial at Philadelphia in 1911. The apparatus is known as the Nichols separator (Pl. II, *B*, p. 33) and with it the dirty sand can be washed and restored to the bed without removing the scrapings to sand washers outside the filters. This machine weighs about 700 pounds and is

[1] Hazen, Allen, and Hardy, E. D., Works for the purification of the water supply of Washington, D. C.: Trans. Am. Soc. Civil Eng., vol. 57, 1906, p. 349.

moved from point to point on the bed on short lengths of channel rails which can easily be shifted by four men. It has been demonstrated at Philadelphia that with one of these machines it is possible to clean and replace 10 cubic yards of sand an hour, using 1,200 gallons of water to the cubic yard of sand washed. The cost of sand washing by the new method is materially lower than formerly, when the sand was first ejected to the courts, there washed, and afterwards restored to the filter. By the old method the cost for scraping, removing, and washing the sand was 52 cents a cubic yard, and for restoring the washed sand to the bed 24 cents a cubic yard, a total of 76 cents a cubic yard. With the Nichols separator, where the sand is washed and restored at the filter, the total cost during two years' operation of the machine was about 50 cents a cubic yard. Furthermore, less than half as much water is used in the new process.

Still another method was carefully studied at New York during 1907 and 1908. This device is known as the Blaisdell filter-sand washing machine, and was first given a trial at Yuma, Ariz., on a slow sand filter treating the turbid waters of Colorado River. It had been in successful operation at Yuma for about four years before it was investigated in connection with the experimental slow sand filters treating the Croton water supply of New York City at high rates of filtration. The results of the investigation, carried on at Jerome Park in 1907 and 1908, were so favorable that the machine was recommended for adoption in the proposed new Croton filtration project. It was also adopted and is in successful use at the Wilmington, Del., filtration plant. (See Pl. III.)

In construction this washing machine is comparatively simple. It consists of an inverted box about 4 feet square and 2 feet deep. The box contains a revolving hollow axle and a hollow head from which hollow teeth project. In operation the box is sunk in the water of the filter to the surface of the sand and is held in position and operated from a platform above. The platform is movable on rails supported by the walls of the filter. By means of electrically driven mechanism controlled by one operator the box can be lowered and raised and moved backward, forward, and sideways at will. In operation the box is made to slide over the surface of the sand at a speed of about 10 feet a minute and at the same time the hollow teeth are revolved, agitating the sand mechanically. Water is introduced into the hollow axle, head, and teeth under a pressure of 10 to 20 pounds to the square inch and passes in fine streams into the sand. A suction pump connected with the top of the box draws away just a little more water than is supplied through the teeth, and thus carries away and discharges to a sewer all of the dirt which has been stirred and washed from the sand. For further details regarding this



FILTER AT WILMINGTON, DEL., WITH BLAISDELL SAND-WASHING MACHINE.

Photograph furnished by Board of Water Commissioners, Wilmington, Del.

machine the reader is referred to an article by William B. Fuller in the Engineering News.[1]

The possibilities of such a machine as this are readily apparent By other methods of cleaning a slow sand filter it is first necessary to drain the filter, which consumes much time, and afterwards to set a gang of men at work scraping off the clogged surface layer, and then carefully to refill the filter from below. This machine makes it possible to clean the sand layer without draining the filter. The time saved by the new process may be explained briefly as follows:

Assume that a slow sand filter operating at a rate of 3,000,000 gallons daily to the acre, exclusive of the time used in cleaning, yields a daily average of 60,000,000 gallons. Make a further conservative assumption that three days are required for the scraping, washing, and restoring operations under the older methods. This is equivalent to the assumption that the filter will be out of service 13 per cent of the time, and that the reserve filter area required to maintain the normal yield under these circumstances can not safely be less than 15 per cent of the total area actually required. Experiments made in connection with the New York City water supply have established the fact that a slow sand filter can be operated up to a daily rate of 10,000,000 gallons to the acre and produce an effluent of satisfactory quality. If such a filter were cleaned according to the older methods it would be out of service 33 per cent of the time if operated at the 10,000,000-gallon rate, and it would be unsafe to install a reserve filtration area less than 50 per cent of that required to supply the average daily demand for water. The New York investigation showed further that by use of the sand-washing machine, and by adjusting the unit area of the separate filter beds so that they can be effectively cleaned, the 10,000,000-gallon rate can be maintained. Suspension of operation for each filter would not exceed two or three hours. In other words, by the use of the washing machine a great reduction in first cost of the filter could be accomplished by the consequent diminishing of the reserve area required, which would also involve a proportionate reduction in the area of land that must be purchased for a filter site. The final result is therefore a smaller necessary filtration area with all the consequent advantages as to first cost and maintenance. Experimental work with these machines is still in progress, and further economies and advantages will no doubt result.

FILTER SURFACE RAKING AT PITTSBURGH.

When a filter becomes clogged at the surface by an accumulation of mud and miscellaneous matter derived from the unfiltered water, it is the common practice in rapid filter operation, where the filters are

[1] Eng. News, vol. 59, No. 11, 1908, pp. 287–288.

circular in plan and are stirred by a mechanical agitator when they are washed, to trail the teeth of the rakes lightly over the surface of the filter, thereby breaking up the surface accumulation and prolonging the "run" to a greater or lesser extent. Until recently such a procedure had not been applied to slow sand filters, it being considered necessary to drain the filter and actually remove a portion of the surface of the bed. Experience at Washington, where raking of filter beds was first tried on a large scale, showed that the process prolongs the periods of service of the slow sand filters between actual scrapings.[1]

Surface raking of slow sand filters was first tried at Pittsburgh in the autumn of 1910. The procedure consists in partly draining a filter and in sending men into it to score the surface lightly with common garden rakes having teeth about 1 inch long. An acre bed can be treated in this way by four men in about eight hours at a cost of about $8. The filter is then refilled and filtration resumed.

The important result of this operation is that the filtering capacity of the bed is almost as effectively restored as it would have been by a scraping, which would have consumed much more time and cost a great deal more money. A second raking is much less effective, as might be expected, and a third raking is of little use. The immediate result is to cause a deeper penetration of the suspended matter into the filter. This was expected; but at Pittsburgh, as at Washington and Philadelphia, such penetration was found by repeated examinations not to extend deeper than about 2 inches from the surface. When the filter is ultimately scraped, a deeper layer has to be removed, of course, but it is manifestly cheaper to remove one deep layer at one operation than to remove separately several thinner layers of an equal aggregate thickness.

It has been clearly demonstrated at Pittsburgh, as at other places where the raking process has been used, that the filter is in no way injured, nor is its hygienic efficiency diminished. This somewhat radical departure from standard practice in slow sand filter operation is one of the most valuable steps taken in the field of water filtration in many years. Without increasing the rate of filtration it makes possible larger yields per unit area of filter surface and materially reduces the total loss of time for cleaning the filters. Smaller areas of filter surface will be required than formerly in order to obtain a stipulated daily volume of filtered water, which means economy in construction. Fewer actual scrapings in a year, made possible by relatively inexpensive surface rakings, means economy in operation. From the results obtained thus far it appears certain that in this de-

[1] Proc. Am. Soc. Civil Eng., vol. 36, No. 10, Dec., 1910.

partment of filter operation alone a saving of about $50,000 will be shown for 1911 at Pittsburgh.

RELATION OF FILTER CLEANING TO RATE OF FILTRATION AND EFFICIENCY OF SLOW SAND FILTERS.

The regulations of the German Imperial Board of Health, based largely on the thorough studies of Peifke, place the maximum rate at which water should be passed through a slow sand filter at 60 gallons a day to the square foot of filtering surface, a rate which has been almost universally adopted throughout Europe and America, This corresponds to a column of water 4 inches in depth per hour, or a total yield to the acre of filtering surface of 2,614,000 gallons daily.

The rate of filtration is obviously controlled by the fineness of the sand grains comprising the filter and the quality of filtered water desired. Long experimentation and practical operation of large filters seemed to make it plain years ago that no slow sand filter, no matter what character of water it was called on to treat, should be expected to yield more than about 3,000,000 gallons of water to the acre daily under the best conditions of friction and loss of head in the filter and of physical and hygienic quality of the filtered water. Furthermore, it must be remembered that this yield is based on the actual rate of filtration while the filter is in operation. During a considerable portion of the time (from 10 per cent upward) the filter is out of service for cleaning, and the net rate of filtration through a period of several months will show a reduction proportionate to this time. Generally speaking, it has been considered proper in planning a slow sand filter to figure on a reserve area of 15 to 25 per cent in excess of that required when all of the filters are in active service. Naturally this feature, involving a materially increased first cost of the plant, has been an incentive to engineers to find some method whereby filters of this type can be more speedily cleaned and a less area of reserve filters be required.

That filters of this type can be successfully operated at rates materially higher than 3,000,000 gallons to the acre daily has been clearly demonstrated by the good results obtained in practice at Zurich, Switzerland, Yokohama, Japan, and elsewhere. Carefully conducted experiments at Lawrence, Mass., Louisville, Ky., Cincinnati, Ohio, New Orleans, La., Springfield, Mass., and New York, N. Y., have indicated clearly that where the raw water is given proper preparatory treatment much higher rates than 3,000,000 gallons to the acre daily are perfectly feasible without endangering the quality of the filtered water. As before stated, the great drawback to the adoption of higher rates has been the more speedy clogging of

the sand surfaces and the consequent increased cost for reserve filter area. Obviously higher rates must cause speedier clogging of the filters, but generally speaking the yield between scrapings of the filters, whether operated at rates of 3,000,000 or 6,000,000 or even 9,000,000 gallons to the acre daily, will be approximately the same. The chief difficulty has been the time required for cleaning the filters. The last few years have been fruitful in showing that certain well-defined advances are being made in the more rapid cleaning of slow sand filters, as indicated in the foregoing pages under the caption "Machines for sand washing."

COST OF CONSTRUCTION OF SLOW SAND FILTERS.

Many attempts have been made to compare the cost of construction of slow sand filter plants in this country, but local conditions control so largely that comparative figures have little value. To illustrate this point a few examples are given.

ASHLAND, WIS.

The plant at Ashland, Wis., was built in 1895 and was the first slow sand filter in America to be covered by masonry. It is located near the shore of Lake Superior, and on that account it was necessary to build a pile bulkhead around three sides of the plant. The bottoms of the filters are below the lake level and consequently a coffer-dam was required during construction. The filters are three in number and are built of concrete and brick. The roofs are groined elliptical brick arches and rest on brick pillars. The filter bottoms are of concrete. The work was all done by day labor and the total cost of construction was $40,178, or $80,356 per acre of filtering surface.

BERWYN, PA.

The filter at Berwyn, Pa., was built in 1898 and consists of three filter units, all uncovered, having a total area of 0.5 acre. The walls of the filter are of rubble masonry backed up with earth and the floor is of concrete. The total cost of construction was $18,536, which corresponds to $33,070 per acre of filtering surface, or $12,000 per million gallons daily capacity.

NYACK, N. Y.

The filter at Nyack, N. Y., was built in 1899 and consists of two units, both uncovered, having a total area of 0.38 acre. It is located in a swamp near a creek from which the supply is drawn, and in order to get the water to the filters by gravity it was necessary to excavate for the filter beds 10 feet of wet tenacious clay. The con-

crete and brick side and division walls are supported on piles. The work was done by contract and the total cost was $29,094, which is equal to $76,550 per acre of filtering surface, or about $39,000 per million gallons daily capacity. It should be mentioned that this cost includes a small filtered-water basin having a capacity of about 3,500 gallons.

SUPERIOR, WIS.

The plant at Superior, Wis., was built in 1899 for the purpose of removing iron in the water from driven wells. Because of the fact that the water was bacterially satisfactory a high rate of filtration (10,000,000 gallons an acre daily) was used.

The plant consists of three units having a total area of 0.5 acre and a filtered-water basin of about 300,000 gallons capacity. The floors and walls of the filter tanks and filtered-water basin are of concrete and both are under one groined-arch concrete roof, which rests on brick piers and is covered with 2 feet of earth. All excavation was in red clay. The works were built by day labor and the total cost was $89,484.

ALBANY, N. Y.

The plant at Albany, N. Y., has a daily capacity of 15,000,000 gallons; it was completed in 1899 and originally consisted of a pumping station and intake, sedimentation basin, slow sand filter, and filtered-water reservoir. Recently, roughing filters have been added to aid in the preparation of the water for final filtration. The cost of this plant when it was built, as given by the designer, Allen Hazen, was as follows:[1]

Cost of slow sand filtration plant at Albany, N. Y.

Land	$8,290
Pumping station and intake, complete	49,745
Filters, eight beds, each 0.7 acre in area, covered; sedimentation basin, capacity 37,000,000 gallons; and filtered-water reservoir, complete	324,217
Conduit and connections with Quackenbush Street pumping station	86,638
Engineering and contingencies	31,000
Total approximate cost of works	499,890
Cost of filters, per acre	45,600
Cost of uncovered sedimentation reservoir per million gallons capacity	4,100
Cost of filtered-water reservoir per million gallons capacity	15,000
Cost of filters per million gallons gross daily capacity	15,200
Cost of works per million gallons daily capacity	33,320

[1] Trans. Am. Soc. Civil Eng., vol. 43, 1900, p. 294.

WASHINGTON, D. C.

Summarized data as to the construction cost of the 75,000,000-gallon slow sand filter plant at Washington, D. C., taken from a paper by Allen Hazen and E. D. Hardy,[1] are as follows:

Cost of slow sand filtration plant at Washington, D. C.

Land	$619,900
Pumping station, including intake, Venturi meter, electric generating plant, stack, etc., complete	183,600
Twenty-nine filters, covered, each 1 acre in area, complete	2,197,000
Filtered-water reservoir, capacity 14,200,000 gallons, including gatehouse and regulating apparatus, complete	150,000
Lower gatehouse and pipe line	24,300
Engineering and clerical work	181,500
Total cost of works	3,356,300
Total cost, excluding land	2,736,400
Cost of filters per acre	75,700
Cost of filtered-water reservoir per million gallons capacity	10,600
Cost of filters per million gallons gross daily capacity	25,250
Cost of plant per million gallons daily capacity	44,750

PITTSBURGH, PA.

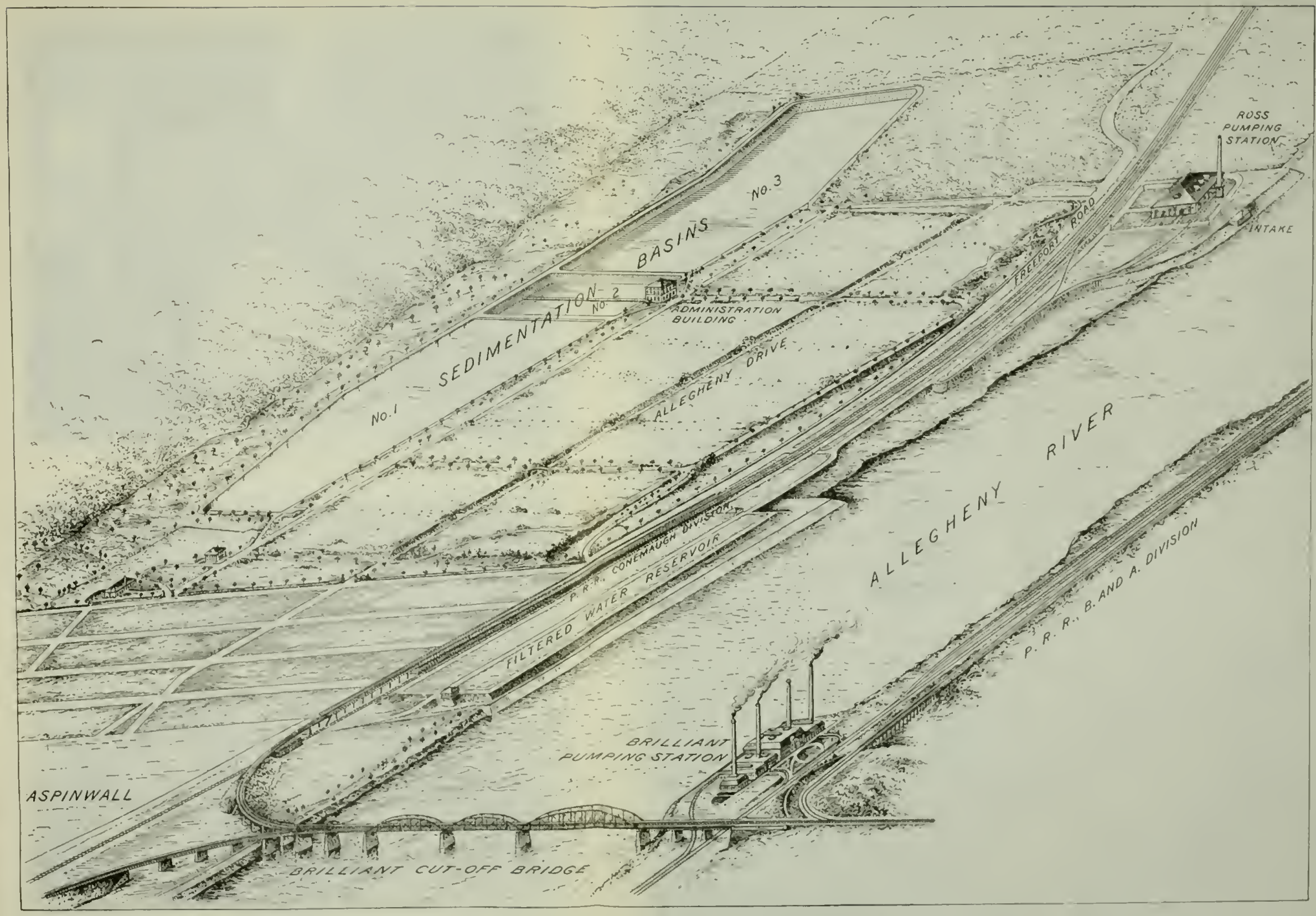
The works at Pittsburgh, Pa., consisting of covered slow sand filters, covered filtered-water basin, and open sedimentation reservoirs, were completed in 1908 (Pl. IV). The total cost as awarded the contractors by the arbitrators in July, 1910, and not including engineering and a small portion of daywork done by the city, was as follows:

Cost of slow sand filtration plant at Pittsburgh, Pa.

River crossing and connections	$298,589
Low-lift pumping station	357,513
Low-lift pumping machinery, boilers, etc	284,169
River well and intake	207,673
Brilliant pumping station (additional machinery)	221,472
Pipe lines to Highland reservoir	555,250
Filters[2] (46 1-acre units, covered) and open sedimentation basins	3,586,245
Filtered-water reservoir, 45,000,000 gallons capacity	460,060
Total cost of works	5,970,971
Cost of filters (including settling basins) per acre	78,000
Cost of filtered-water reservoir per million gallons capacity	10,200
Cost of filters (including settling basins) per million gallons daily capacity	26,000
Cost of plant per million gallons daily capacity	42,600

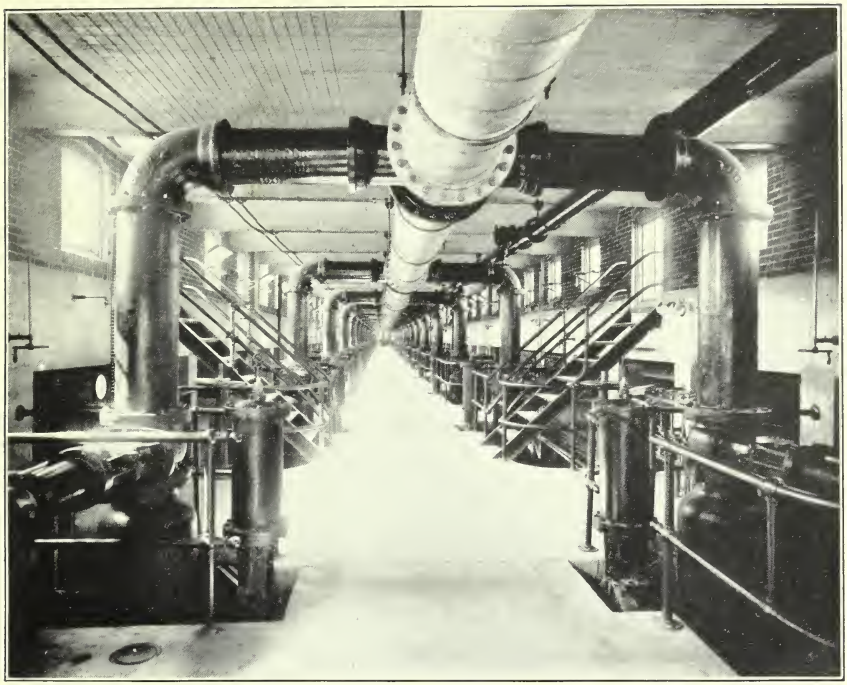
[1] Trans. Am. Soc. Civil Eng., vol. 57, 1906, p. 307.

[2] Ten more acres of filters have since been built but have not been placed in service.



ISOMETRIC VIEW OF FILTRATION WORKS, PITTSBURGH, PA.

From print furnished by Bureau of Filtration, Pittsburgh, Pa



A. OPERATING GALLERY OF THE TORRESDALE PREFILTER, PHILADELPHIA, PA.

Photograph furnished by Department of Public Works, Philadelphia, Pa.

B. OPERATING FLOOR AND RAPID SAND FILTERS OF THE CHINCHILLA FILTRATION PLANT, SCRANTON, PA.

Photograph furnished by Scranton Gas & Water Co.

PHILADELPHIA, PA.

The works at Philadelphia (Pl. II, p. 33, and Pl. V, *A*), the largest in the world, are not completed as a whole. There are five separate plants, four of which are completed and one is still in process of construction. The following construction costs of the several plants built and the one still building are taken from the report of the Bureau of Water, Philadelphia Department of Public Works, for 1909:

Lower Roxboro plant.—The plant at Lower Roxboro has a capacity of 12,000,000 gallons daily. The works include a pumping station, a sedimentation basin of about 12,000,000 gallons capacity, 11 covered preliminary filters of slag and sponge containing about 0.28 acre in total filtering area, 5 covered slow sand filters, about 2.7 acres in total filtering area, and a covered filtered-water reservoir of 3,000,000 gallons capacity. Total cost, $580,000; cost per million gallons daily capacity, $48,330.

Upper Roxboro plant.—The capacity of the Upper Roxboro plant is 16,000,000 gallons daily. The works include an administration building, a low-lift pumping station with equipment, eight covered filters, about 5.6 acres in total filtering area, and a filtered-water reservoir of 8,000,000 gallons capacity. Total cost, $1,080,000; cost per million gallons daily capacity, $67,500.

Belmont plant.—The capacity of the Belmont plant is 67,000,000 gallons daily. The works consist of two settling basins of 72,000,000 gallons total capacity, 9 preliminary filters of coke and sponge, 18 covered final filters about 13.25 acres in total area, and a filtered-water basin of 16,500,000 gallons capacity.

Cost of Belmont slow sand filtration plant, Philadelphia, Pa.

Total cost of works	$3,292,000
Cost per million gallons daily capacity	49,120
Cost of sedimentation basins per million gallons of capacity, about	8,340

Torresdale plant.—The capacity of the Torresdale plant is 240,000,000 gallons daily. The works include an intake, gatehouses, and pumping station, 120 covered mechanical preliminary filters about 3.35 acres in total area, and a filtered-water basin of 50,000,000 gallons daily capacity.

Cost of Torresdale slow sand filtration plant, Philadelphia, Pa.

Total cost	$9,208,000
Cost per million gallons daily capacity	38,370
Cost of intake	225,000
Cost of pumping stations, including building and pumps	723,000
Cost of preliminary filters per acre, about	346,300
Cost of preliminary filters per million gallons daily capacity	4,830
Cost of final filters per acre	145,000
Cost of final filters per million gallons daily capacity	39,600

Queen Lane plant.—The Queen Lane plant, now building, is to have a capacity of 70,000,000 gallons daily. The works will include 40 covered preliminary filters about 1.7 acres in total area, 22 covered final filters about 16.7 acres in total area, and a filtered-water basin of 50,000,000 gallons capacity. Estimated cost of works, $1,900,000; cost per million gallons daily capacity, about, $27,100.

OSAKA, JAPAN.

The water-purification works at Osaka, Japan, having a daily capacity of about 25,000,000 gallons, include open sedimentation basins and slow sand filters. One of the sedimentation basins, completed in 1903, of about 10,000,000 gallons effective capacity, cost $83,370, exclusive of the cost of the land. One of the uncovered slow sand filters, finished in the same year, has a filtering area of about 1.45 acres and cost $45,050, or about $31,000 per acre of filtering surface.

SUMMARY.

If the examples given can be considered as approximately representative, the average cost of building a slow sand filter is about $60,000 per acre of filtering surface. If conditions are favorable the cost may be less; if they are unfavorable it will be greater.

If a slow sand filter costs $60,000 an acre to build, and if the gross capacity of a 1-acre filter is 3,000,000 gallons daily and its net capacity about 2,500,000 gallons daily, then in a community which consumes 125 gallons per capita daily an acre of filter will supply 20,000 people. If the cost of the filter is $60,000, the first cost to each consumer will be $3. At 6 per cent the interest charges on this investment will be 18 cents per capita per annum. Settling basins and filtered-water reservoirs may increase the first cost of the works to about $4 per capita, and on this the annual interest at 6 per cent would be 24 cents per capita. These figures are of necessity approximate, but may serve fairly well to indicate what purification plants, including slow sand filters, will cost each taxpayer.

During epidemics of typhoid fever it is the custom in this country for the local health authorities to send out a wholesale warning that all water used for drinking should be boiled. Such warnings are heeded by the thinking citizen for at least six weeks after publication. Now, if gas is used to boil this water at $1 a thousand cubic feet, it may be estimated that the cost of making the drinking water safe during these six weeks will be about 21 cents per capita on the basis that a person will drink half a gallon of water a day. An ordinary gas-range burner will use about 20 cubic feet of gas per hour, and at least 25 minutes will be consumed in bringing a gallon vessel of water to a boiling point and in maintaining it that point until the water is sterile of bacteria. The per capita cost for boiling drinking water for six weeks may be roughly estimated as about the same as

that given above as the annual per capita interest charge on the first cost of water-purification works, which will protect the water consumer from water-borne diseases not only at the time of epidemics but every day in the year.

COST OF OPERATION AND MAINTENANCE OF SLOW SAND FILTERS.

The cost of operating slow sand filters and maintaining them in good repair will vary considerably, depending on the size of the plant and on the character of water the works are called on to purify. In a general way such costs will average about $3 for each million gallons of water treated, a sum which does not include interest on the investment or pumping charges. For the sake of comparison the actual annual cost of operation of several slow sand filter plants is given.

ALBANY, N. Y.

The cost of operation of the Albany filter plant, which treats the frequently muddy water of Hudson River, is well shown in the following table. These data were kindly furnished by Mr. H. J. Deutschbein, superintendent Albany Bureau of Water.

Comparison of cost per million gallons of single and double filtration at Albany, N. Y.

	Single filtration, 1899–1907 (8 years).	Double filtration, 1910–11 (11 months).
Sedimentation basin: Removing sediment	$0.01	$0.03
Slow sand filters:		
Scraping sand	.17	.07
Removing sand	.33	.09
Washing sand	.27	.04
Replacing sand	.30	
Reforking sand	.03	.01
Wash water	.08	(a)
Incidentals and lost time	.38	.54
Removing ice		.03
Supplies and repairs	.13	.19
Total	1.69	.97
Preliminary filters:		
Attendance		.45
Washing sand		.08
Supplies		.05
Total		.58
Total cost of filtration	1.70	1.58
Pumping:[a]		
Enginemen and firemen	1.13	1.19
Labor	.13	.03
Supplies	1.26	1.36
Total cost of pumping	2.52	2.58
Office: Superintendence and watchmen	.50	.30
Laboratory:		
Chemist	.25	.24
Assistants	.01	.22
Supplies	.06	.10
	.32	.56
Total cost per million gallons	5.04	5.02
Average quantity filtered per day, gallons	13,200,000	20,342,000

[a] Cost of wash water is included in cost of pumping.

PHILADELPHIA, PA.

The one hundred and eighth annual report of the Philadelphia bureau of water, F. C. Dunlap, chief engineer, gives the cost of operation of the four filtration plants now in operation in Philadelphia as follows:

Cost of operation of Philadelphia slow sand filters per million gallons of water filtered.

Plant.	Lower Roxboro.	Upper Roxboro.	Belmont.	Torresdale.
Average million gallons filtered daily	13	14	38	202
Prefilters: Cost for filter attendants, labor, maintenance, and repairs	$1.45	.....	$0.60	$0.26
Final filters: Cost for office, filter attendants, sand handling, labor, and laboratory	2.79	$3.18	2.63	1.44
	4.24	3.18	3.23	1.70

PITTSBURGH, PA.

For the year ending January 31, 1911, the cost of operation of the Pittsburgh filtration works, according to Charles A. Finley, superintendent Pittsburgh bureau of water, was as follows:

Cost of operation per million gallons of water filtered at Pittsburgh, Pa.

Supervision, filter attendants, and laboratory	$1.39
Filter cleaning	2.00
Care of galleries, buildings, and grounds	.80
	4.19

The cost of filter operation at Pittsburgh, as shown above, was somewhat high in 1910, but recent improvements made in the sand-handling department will effect a substantial decrease in this figure for 1911.

WASHINGTON, D. C.

The cost for labor and supplies in the operation of the 75,000,000-gallon slow sand filter plant at Washington, D. C., is given for 1909–10 by Capt. W. T. Hannum, Corps of Engineers, the charge being itemized as follows:

Cost of operation per million gallons of water filtered at Washington, D. C.

Offices and laboratory	$1.13
Filter operations (sand handling, repairs, etc.)	.75
Care of grounds, etc	.53
	2.41

TOTAL COST OF SLOW SAND FILTRATION.

The statement has already been made that to construct slow sand filter plants will cost about $60,000 an acre. The net capacity of an acre slow sand filter is ordinarily about 2,500,000 gallons daily, which

corresponds to a cost of $24,000 per million gallons capacity. Settling basins and filtered water reservoirs will increase this amount to about $30,000, which, at 6 per cent, corresponds to a fixed charge of $4.93 a million gallons. Adding to this a fairly average sum for operating cost makes the total cost for filtered water, exclusive of pumping charges, about $8 a million gallons.

On a basis of 125 gallons per capita daily consumption, the actual cost of water filtration would therefore be about 36 cents per capita per annum.

RAPID SAND FILTRATION.

GENERAL DESCRIPTION.

Rapid sand filtration first attracted attention as a method for purifying public water supplies in 1885, when a rapid filter plant was built to treat the supply of Somerville, N. J. Since that time this method has come into use in more than 350 cities in different parts of the world and supplies a total daily demand of considerably over 700,000,000 gallons. The largest plant of this type is installed at Cincinnati, Ohio, and has a daily capacity of 112,000,000 gallons. Others are located at Columbus, Ohio, capacity 30,000,000 gallons daily; Hackensack, N. J., capacity 24,000,000 gallons; Harrisburg, Pa., capacity 20,000,000 gallons; Little Falls, N. J., capacity 32,000,000 gallons; Louisville, Ky. (Pl. VI), capacity 36,000,000 gallons; Toledo, Ohio, capacity 39,000,000 gallons; and New Orleans, La. (Pl. VII), capacity 40,000,000 gallons. Among the larger rapid filter plants under construction in 1911, were those at Minneapolis, Minn., daily capacity 39,000,000 gallons, and at Grand Rapids, Mich., daily capacity 16,000,000 gallons.

Of the three score rapid filter plants in foreign countries the largest is that at Alexandria, Egypt, capacity 12,000,000 gallons daily. Similar works of even greater capacity are under construction at Kyoto, Japan, and at Cairo, Egypt.

The essential differences between rapid sand filters and slow sand filters are as follows: In the rapid sand filters, the filter units are much smaller; the sand grains comprising the filter bed are much coarser; a coagulant is always used in preparing the raw water for final filtration; the rate of filtration is in round numbers forty times that ordinarily used in slow sand filters; and the whole filter bed, when dirty, is cleaned in the tank itself by forcing water upward through the sand instead of scraping off the surface layers as in slow sand filters.

Up to 1902 rapid sand filters were of more or less uniform design. They were contained in wooden or steel tanks of comparatively small diameter, and the more economical concrete construction had not as

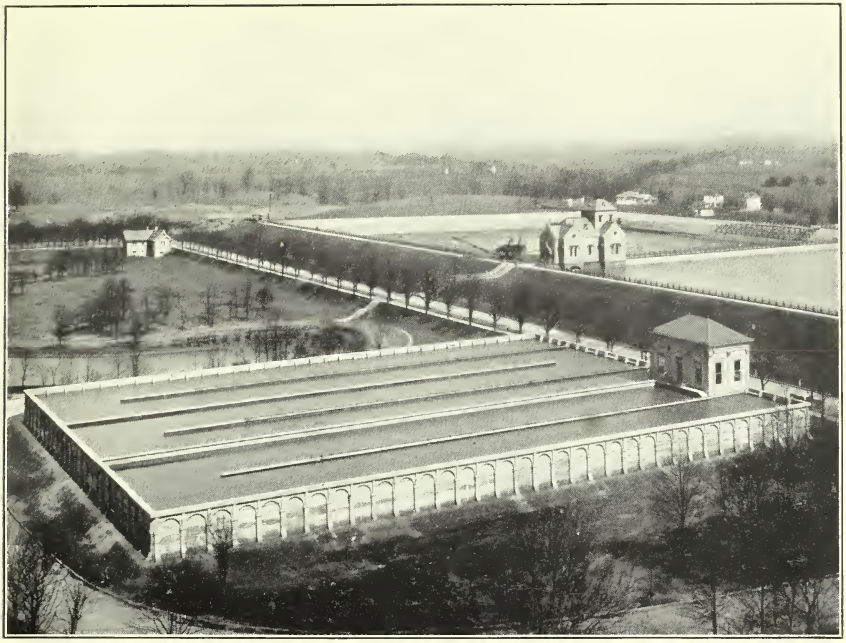
yet been attempted. At the commencement of the classic investigations into this process of water purification, conducted at Louisville, Ky., under George W. Fuller, in 1895–1898, even the process itself had not proved its usefulness in the purification of large volumes of water. Provisions for adequate preparatory treatment of the raw water were rarely made, and the whole subject of the suitable design and operation of such works was but little understood.

The need of adjusting the design of rapid filter plants to meet local requirements began to be fully realized when the plant at Little Falls, N. J., was built in 1902 for the East Jersey Water Co. In this plant suitable provision was made for the accurate application of the coagulating chemical (sulphate of aluminum) to the raw water. A basin of adequate size was provided in which coagulation and sedimentation of the raw water could take place. The filter tanks themselves were built of concrete, for the first time, and were rectangular in plan. Improved facilities were installed for agitating the sand layer with compressed air during washing. Neat operating tables, from which all valves could be operated and motors started and stopped by hydraulic power, took the place of the less neat and convenient wheel stands. With the Little Falls plant the modern ideas of proper design for rapid filter plants began to be realized, and its construction marked a most important epoch in municipal water filtration.

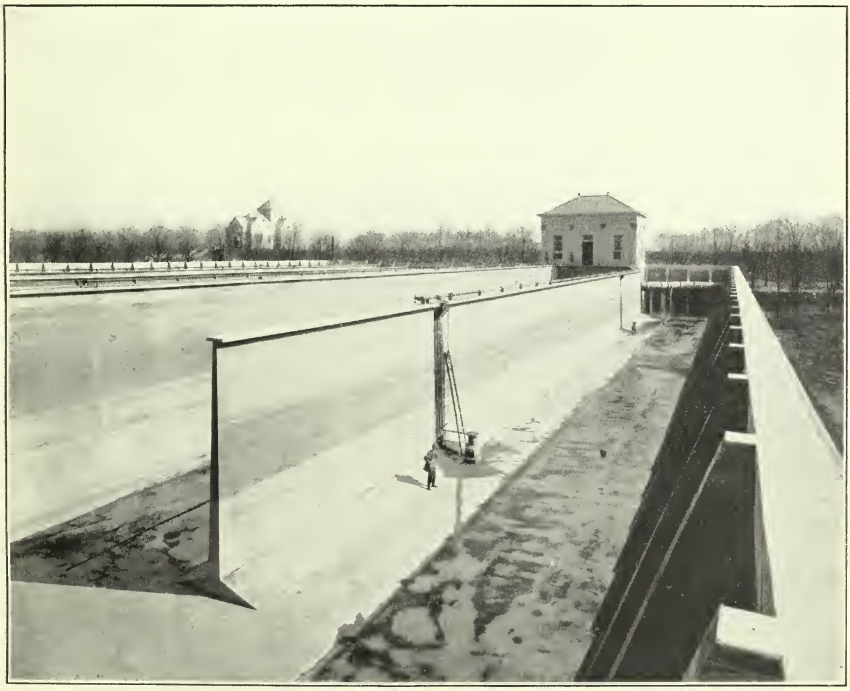
Nearly all rapid filter plants are now built of concrete, although wooden and steel tanks are still used for small installations. The filter tanks are ordinarily built monolithic, and embedded in the floor of the tanks is the underdraining system, composed of perforated pipes or strainer cups, designed to permit the filtered water to pass out without allowing sand to escape and to permit an even distribution of water throughout the sand layer when the filter is being washed. Over the strainer system a shallow layer of coarse sand or gravel is placed, and on this rests the sand layer which forms the filter proper.

When the raw water has been sufficiently clarified by coagulation and sedimentation it is passed on to the surface of the filter, over which water ordinarily stands to a depth of several feet, and allowed to pass downward through the bed at a rate of 100,000,000 to 120,000,000 gallons an acre daily, such rates being automatically controlled by special devices. This corresponds to a rate of 2,310 to 2,760 gallons a day on 1 square foot of filtering surface.

The water applied to the filter always contains a considerable amount of coagulated matter, such as mud, vegetable stain, and bacteria, which is retained at or near the surface of the bed. As operation is continued the frictional resistance in the sand layer increases to a point where it is necessary to close the filter for washing. At such times the water standing over the bed is drained down to the level of the overflow gutters, which are located a foot or more above the



A. BIRD'S-EYE VIEW.



B. VIEW SHOWING DETAILS.

COAGULATING BASINS AT LOUISVILLE, KY.

Photographs furnished by Louisville Water Co.

FILTRATION PLANT AT NEW ORLEANS, LA.

sand layer, and filtered water is then forced upward through the filter, being evenly distributed by means of the strainer system. The material which has accumulated on the top of the sand is thus washed out, and the dirty wash water overflows into the gutters, thence to pass to the sewer. Such a washing operation ordinarily consumes about 10 minutes from the time the filter is closed down until it is again thrown into service.

The rapid filters just described are the type more commonly used; they are known as "gravity" filters and are contained in open tanks.

There is another type, known as "pressure" filters. Such filters are contained in closed steel shells. This type of filter is more extensively employed for household and industrial use, and in some places it is found to be more economical and convenient than the gravity filter. The largest municipal plants of the pressure type are located at Davenport, Iowa, capacity 9,000,000 gallons daily, and at San Diego, Cal., capacity 5,000,000 gallons daily.

COAGULATING CHEMICALS.

The chemicals most commonly used for the coagulation of water are compounds of aluminum and iron, and of these potash alum, sulphate of alumina, alumino-ferric, and sulphate of iron are the most extensively employed.

The manufacture of alum is of great antiquity, and for many centuries this chemical has been used in far eastern countries for coagulating water as an aid to clarification. The manufacture of aluminum sulphate from bauxite and alum clay is of more recent origin. The process of making alumino-ferric from bauxite was patented by P. and F. M. Spence in 1875. The sulphate of iron used in water coagulation is for the most part a by-product of iron and steel industries.

The choice between the different coagulating chemicals is properly based on their efficiency as coagulants, and this refers directly to the percentage of available aluminum or iron which they contain. Potash alum, sulphate of aluminum, and alumino-ferric cost about 1 cent a pound; sulphate of iron costs about half a cent a pound. In this country sulphates of aluminum and iron are the most widely employed in water purification, but at the waterworks at Tokyo, Japan, potash alum is used. Sulphate of aluminum is the coagulant in the works at Alexandria, Egypt, and also in practically all rapid filter plants in Europe, India, and Egypt, except at the waterworks at Calcutta, India, where alumino-ferric is used.

In composition these chemicals show considerable variation, but they may be bought on a basis of a guaranteed percentage of available alumina or iron oxides. The essential feature is that the chemi-

cal shall be basic, that is, shall contain more aluminum or iron than the equivalent of the sulphate radicle present. The approximate composition of these chemicals now on the market is as follows:

Approximate percentage composition of coagulating chemicals.

Constituent.	Pure potash alum.	Sulphate of aluminum.	Alumino-ferric.	Sulphate of iron.
Matter insoluble in water	.....	0.30	0.06	0.50
Alumina (Al_2O_3)	10.77	17.00	14.26	.....
Iron oxides (Fe_2O_3 and FeO)	.....	.25	.60	57.50
Potash (K_2O)	9.93	.....	.....	.....
Sulphur trioxide (SO_3)	33.76	38.70	35.81	28.80
Water (H_2O)	45.54	43.75	49.27	13.20

When potash alum, sulphate of aluminum, or alumino-ferric are applied to a turbid water the chemical is rapidly decomposed. The strong sulphate radicle of the chemical displaces the weak carbonate or bicarbonate radicle in the water, and an equivalent amount of carbon dioxide is liberated. The white, insoluble, and gelatinous aluminum hydrate that is formed absorbs the dissolved color and envelops and brings together into comparatively large aggregates the mud and the bacteria in the water. These flocks of coagulated matter are removed with comparative speed by subsidence.

Generally speaking, the application of these coagulating chemicals to a water will bring about a slight increase in the amount of incrustants in the water and a decrease in temporary hardness. The total hardness of the water—that is, the sum of the temporary hardness and the incrustants expressed in terms chemically equivalent—will remain unchanged. The increase in incrustants has some significance as regards corrosion of uncoated iron and incrustation in boilers; but, practically speaking, these are factors of comparatively little importance in view of the relatively small amounts of the coagulating chemical ordinarily employed.

Most surface waters naturally contain more than sufficient carbonate and bicarbonate radicles to make possible complete decomposition of the chemical which is applied for coagulation. In some waters, however, the natural alkalinity is so low, particularly at times of floods, that this is not true, and for such waters it is necessary to make up the deficiency by applying soda ash or lime water before the coagulant is added.

Sulphate of iron, known commercially as copperas, is obtained in two grades, namely, the ordinary commercial by-product from iron and steel manufacturing, and the higher-grade sugar copperas manufactured by a vacuum crystallizing process.

The use of copperas in water purification introduces more complicated features than alum compounds, chiefly for the reason that

lime is required for the precipitation of the iron. When added to a natural water the copperas is decomposed somewhat like alum except that the formation of the hydrate of iron takes place very slowly. By adding lime in the form of limewater or milk of lime rapid formation of insoluble iron hydrates is induced. In general terms it may be stated that to obtain satisfactory results from the use of lime and iron as coagulants it is necessary to make use of sufficient lime to neutralize and precipitate the iron. The use of too little lime results in poor coagulation, caused by the incomplete precipitation of the iron, some of which is usually left in solution and appears in the effluent of the filters. The use of too much lime results in the formation of lime incrustants, which deposit in the air and strainer systems and cause much trouble through clogging.

Water treated with lime and iron will show an increase in permanent hardness, as compared with the effect of the use of compounds of aluminum. In general the aluminum salts are considered more satisfactory as coagulants; they remove color from water more rapidly and completely and make it possible to obtain by filtration a more brilliant water than do iron salts.

DEVICES FOR APPLICATION OF COAGULANTS.

No department in a filtration plant is more important than that wherein the coagulating chemicals are applied to the water. To obtain satisfactory results from the plant as a whole and the filters in particular, it is necessary that the application of the coagulating chemicals be at all times under strict and accurate control and be adapted to the quality of the water to be filtered. Material variation in the dose of the chemical applied to the water or in the quality of the water means overdosing or underdosing. The former results in a waste of the chemical and sometimes in undecomposed coagulant in the filtered water, and the latter results in incomplete coagulation and impaired efficiency. Owing to the high rates of filtration used in rapid filters undercoagulated water will leave the filter in a less purified state and will possess an undesirable turbidity. The filter will run longer without washing because of the slower accumulation of coagulated material, but the efficiency will be poor.

The different types of device for the control of the application of chemicals are very numerous and are all designed to be as nearly automatic as possible. The appliances which have given the best results are those wherein provision is made for the application of the solution under a practically constant head through an orifice which can be adjusted at will. The depth of solution over this orifice should not be less than 6 inches, and this depth may be maintained by allowing slightly more of the solution to be delivered into the orifice

tank than is allowed to escape through the orifice, the excess being discharged back into the main solution tank through an overflow, or by means of a float valve (Pl. VIII, *A*, p. 60). The overflow is by all odds the more reliable.

The sulphates of iron and aluminum have a corrosive action on almost all metals, and it has been found advisable to make all of the metal parts which come in contact with the solutions of lead, copper, or special bronze. It is sometimes found advantageous to use hard rubber piping, valves, and orifices, but the cost may preclude the use of such material. Rubber piping and valves are easily broken, and the cost of replacement may prove no inconsiderable item. Generally speaking, however, the decision as to the kind of metal to use depends on the relative cost of the cheaper iron and its correspondingly higher cost for repairs and replacements and the ease with which repairs can be made, and the higher first cost of more expensive materials and the lower cost for upkeep.

IMPROVED DEVICES FOR OPERATING RAPID SAND FILTERS.

As already pointed out, it was not until 1902 that marked improvement was made in the direction of making easier the manipulation of valves and other apparatus, which has so much to do with the successful and economical operation of a rapid-filter plant. Until that time all valves, without exception, were opened and closed by hand. When a filter required washing, it was necessary to close the influent and the effluent valves, and to warm up the steam wash-water pump preparatory to supplying wash water to the filter. Now the operator moves a lever at an operating table, and by means of hydraulic cylinders valves are opened or closed with practically no manual effort or loss of time (Pl. V, *B*, p. 42). Electrically driven wash-water pumps have largely supplanted the steam pumps, and the operator starts and stops this pump merely by pressing a button at the same operating table. Air compressors, which supply air to the filters during washing for the purpose of agitating the sand layer, have in most large plants taken the place of the steam-driven rotary agitators, and these compressors are also started and stopped by pressing a button on the operating table.

As time savers these various improvements more than pay for themselves, and the neat appearance of the newer plants is a vast improvement over the older plants with their multitude of wheel stands.

FILTER WASHING.

When a rapid filter has become so clogged with coagulated matter that the normal rate of filtration can no longer be maintained, the influent valve is closed and the water standing over the sand layer

is drawn down to the top of the wash-water gutters. The effluent valve is then closed and the wash-water pump is started. This pump forces filtered water up through the sand layer until it is freed of practically all of the accumulated matter. The pump is then stopped, the influent and the effluent valves are opened, and filtration is resumed. In some places the filters are washed by water delivered under the requisite pressure from an elevated tank. (See Pl. VIII, *B*, p. 60.)

During the process of washing a filter it is the practice in the majority of the newer rapid-filter plants to break up the sand layer with compressed air before turning in the wash water in order to facilitate and accelerate the cleaning of the sand grains. In some places, as at Cincinnati, Ohio, and New Orleans, La., no provision is made for agitating the sand layer during washing other than such agitation as is induced by the upward flow of wash water. In the older plants, and in some of those recently built, wherein the filter tanks are circular in plan, the sand is agitated during washing by means of rake teeth attached to arms which revolve, driving the teeth through the sand.

When washing a filter the rate of application of wash water must not be too low, and on the other hand it must not be too high, or sand will be carried from the bed with the wash water. Ordinarily the best rate of application of wash water is about 6 to 8 gallons to the square foot a minute, which corresponds to a vertical rise of about 1 foot a minute. This is equivalent to three to four times the rate of filtration. When wash water is driven upward through a filter bed of normal construction at these rates, the sand layer will rise from 3 to 5 inches, but practically no sand will escape from the bed except during the early stages of operation of a new filter.

Before the modern appliances for facilitating the labor of operation were installed it was not unusual for periods out of service for washing as great as 30 minutes to be recorded, and frequently the time consumed was even longer. In the more recent filters this period rarely exceeds 10 minutes from the time the effluent valve is closed until it is again opened.

CONTROL OF RATE OF FILTRATION.

If uniform rates of filtration are required for the successful operation of slow sand filters, then uniform rates are of even greater importance in rapid sand filters. The reason for this is plain. Slow sand filters are operated at actual rates of about 3,000,000 gallons an acre daily; rapid filters are operated at rates from 30 to 40 times as high as this. A sudden fluctuation in these higher rates means a correspondingly greater shock, and impaired efficiency naturally follows.

Although within certain limits there is no particular objection to the rate of filtration in a rapid filter gradually diminishing, a sudden increase in rate will cause an almost immediate deterioration in the appearance and hygienic quality of the effluent. If the rate increases or decreases slowly and steadily no harm may result, but should the rate increase abruptly, even as much as 20 per cent, the effect of the change will usually be apparent from the inferior appearance of the filtered water.

Therefore, to maintain a constant rate of filtration in the rapid filter, automatic controllers are always used. There are many such devices, but the object of all is to maintain a uniform rate of discharge from the filter independent of the head on the outlet pipe on which the controller is located. Although many improvements in these devices have been made in recent years, the best of them subject the filter to fluctuations in rate of at least 10 per cent. Furthermore, on account of the tendency of floats and butterfly valves in these controllers to stick, such fluctuations may occur within a very few seconds. In drawing up specifications for controllers it is frequently stated that such variations from the normal rate shall not exceed 2 per cent, but this requirement is rarely if ever met. Nevertheless the controllers do practically the work required of them, and without them a rapid filter would be unable to maintain a high standard of efficiency.

COST OF CONSTRUCTION OF RAPID SAND FILTERS.

It is almost as difficult to state the comparative cost of construction of rapid sand filters as of slow sand filters. Local conditions largely govern, and it is possible and feasible to build some plants much more cheaply than others, and at the same time obtain plants which will prove as efficient as those which are more complete and ornate. In illustration of the cost of such plants a few examples of existing works may be given.

LITTLE FALLS, N. J.

The plant at Little Falls, N. J., was completed and placed in operation in the fall of 1902, and here, for the first time, a radical departure was made in the construction of the filters, which are rectangular in plan and built monolithic of reinforced concrete. In fact, the entire plant, including the coagulating and the filtered-water basins, was built of concrete, as were also the walls of the buildings.

The works have a capacity of 32,000,000 gallons daily, and are capable, for short periods, of yielding 48,000,000 gallons daily. The works are so built that the raw water is led by gravity to the coagulating basin from a headrace canal taking water from Passaic River.

From the time the raw water enters the building until the filtered water is delivered to the main pumps which raise the filtered product to the distributing reservoirs, the flow is entirely by gravity. This made it possible to avoid the cost of extra pumping equipment but compelled the adoption of relatively expensive deep structures.

The coagulating and settling basin is 130 by 42 by 43 feet deep on inside lines, and has a capacity of 1,700,000 gallons, thus providing a period of coagulation of about one and one-third hours when the plant is working at its full capacity. The filtered-water basin, located beneath the filters, has an effective depth of about 18 feet and a capacity of about 3,500,000 gallons.

The filter tanks are arranged in two separate galleries over the filtered-water basin. In each gallery there are two rows of 8 filters each, making 32 filters in all. Between and beneath the two rows of filters in each gallery is a pipe gallery, above which is the floor on which the operating tables are located.

In the machinery room, located over the coagulating basin, are rotary blowers for supplying compressed air to the filters while being washed, pumps and devices for applying the coagulant, a storage room for the coagulant, laboratories, wash room, tool room, lockers, and offices. All machinery is operated by electric motors, and current is obtained from generators located in the main pump house.

The raw water is delivered to the filtration works through a 66-inch steel main, which discharges into a concrete standpipe 10 feet in diameter, located at one end of the coagulating basin. The coagulant is applied to the water in this standpipe and is discharged from the bottom into the coagulating basin. The clarified water is collected in a pipe at the other end of the basin and delivered to the filters.

The plant was built entirely by contract and cost as follows:

Cost of Little Falls rapid sand filter plant.[a]

	Total cost.	Cost per million gallons daily capacity.
Coagulating basin and clear-water basin, including piping within the walls and grading the grounds	$172,800	$5,400
Supply and suction pipes inside the structure	25,600	809
Filter tanks, including covers	48,000	1,500
Main building and wings, including floors, piers, and entire superstructure, except the last item	64,000	2,000
Filter equipment complete, including machinery within the buildings	153,600	4,800
Power equipment and outside wiring	25,600	800
	489,600	15,300

[a] Trans. Am. Soc. Civil Eng., vol. 50, 1902, p. 443.

BINGHAMTON, N. Y.

The plant at Binghamton, N. Y., which has a daily capacity of 8,000,000 gallons, was also completed and placed in operation in 1902. It was built by contract. The plant is contained in a brick building 180 by 53 feet, resting on concrete foundations and with a steel-trussed slate roof.

The coagulating and settling basins are two in number, are built of concrete, and have a daily capacity of 200,000 gallons. The filter units, of which there are 12, are each 21½ by 15 feet in area and are arranged in two rows between which is a pipe gallery, covered with an operating platform. The filter tanks are built monolithic of concrete. Beneath the filters is the filtered-water basin, which has a capacity of 350,000 gallons. This is a weak feature in the plant, for the reason that the service is by pumping direct into the mains, and the storage of filtered water thus provided is so small that it was deemed necessary to design the filter-rate controllers so that they might be opened wide in case of fire, an operating feature which must at times impair the efficiency of the plant.

The contract price of the plant, which included an engine room, two centrifugal pumps, tanks, and appurtenances for applying the coagulant solution, an air compressor to supply air to the filters while being washed, and a storage room for chemicals, etc., was $86,292, or about $10,800 per million gallons of daily filtering capacity.

NEW MILFORD, N. J.

The plant at New Milford, N. J., built by the Hackensack Water Co., which supplies water to the city of Hoboken and 33 smaller communities in New Jersey (total population served, about 250,000), was built in 1905 and has a capacity of 24,000,000 gallons daily.

The settling basin of excavation and embankment is 285 by 41½ by 20½ feet deep (height of the water line) and has a capacity of about 12,000,000 gallons. The filters are eight in number and built monolithic of reenforced concrete. Each filter tank is 46 feet 8 inches by 25 feet 10 inches by 9 feet 6 inches deep. The tanks are arranged in two rows on either side of a pipe gallery. Each filter has a capacity of 3,000,000 gallons daily.

The filtered-water reservoir is located beneath the filters. It is built of concrete, has a depth of about 12 feet, and a capacity of 1,200,000 gallons.

A novel feature in this plant is the strainer system. On each side of the central wash-water trough, with a main effluent collector in the center, are four strainer and collector units. The lateral collectors are oval passages 4 inches wide and 5 inches high, formed in concrete blocks which are each 5 feet ⅞ inch by 8½ inches wide and 9

inches high. These blocks, when assembled side by side, form a strainer floor, consisting of a checkerwork of square hopper-shaped depressions 3 inches deep. The bottoms of these depressions are 3 inches square and each supports a strainer, consisting of a square plate of sheet brass, perforated with 137 holes one-sixteenth inch in diameter, and pressed into the form of a flat truncated pyramid. Below the strainer is a pocket about $2\frac{1}{8}$ inches square, connected with the lateral collector by a piece of $\frac{3}{8}$-inch brass pipe. The strainer is fastened down with a $\frac{1}{8}$-inch brass bolt, screwed into a special brass net, set in the concrete at the bottom of the pocket. Each of the eight units of the strainer system has a central main collector to which the oval lateral collectors connect.

The total cost of this plant was approximately $175,000, which included the buildings, filters, and equipment, clear-water basin, wash-water tank, and the necessary machinery within the filter building. Charges for engineering and the cost of the settling basin and of the main pumping station are excluded. The cost for each million gallons' daily capacity for the filter plant proper was about $7,300. When the cost of the settling basin and the charges for engineering are added, it is estimated that the total cost of the plant was about $11,000 per million gallons' daily capacity.

WATERTOWN, N. Y.

The Watertown plant was completed in 1904 and has a capacity of 8,000,000 gallons daily. The filter building is of stone, with slate roof and wooden floors. The filter tanks are eight in number, each 13 by 21 by $8\frac{1}{2}$ feet deep. The coagulating basin and the filtered-water reservoir are located outside the filter building, are covered, and have capacities of 1,000,000 and 8,000,000 gallons, respectively.

The total cost of this plant, exclusive of low-lift pumping machinery, was about $90,000, or $11,250 per million gallons daily capacity. The plant was built by contract.

HARRISBURG, PA.

The Harrisburg plant is another reenforced-concrete plant, completed in 1905 (fig. 1). The capacity is 16,000,000 gallons daily. The coagulating basins are of earth excavation with concrete covers, are located outside the filter building, and have a capacity of 4,000,000 gallons.

The filter building is of reenforced concrete, with brick walls and slate roof, and contains 12 concrete filter units, each 16 by 27 by 9 feet deep. The filtered-water basin, beneath the filters, is of concrete and has a capacity of 700,000 gallons.

The total cost of the plant, including three 12-inch centrifugal pumps and pumping station, was $216,000, corresponding to $13,500

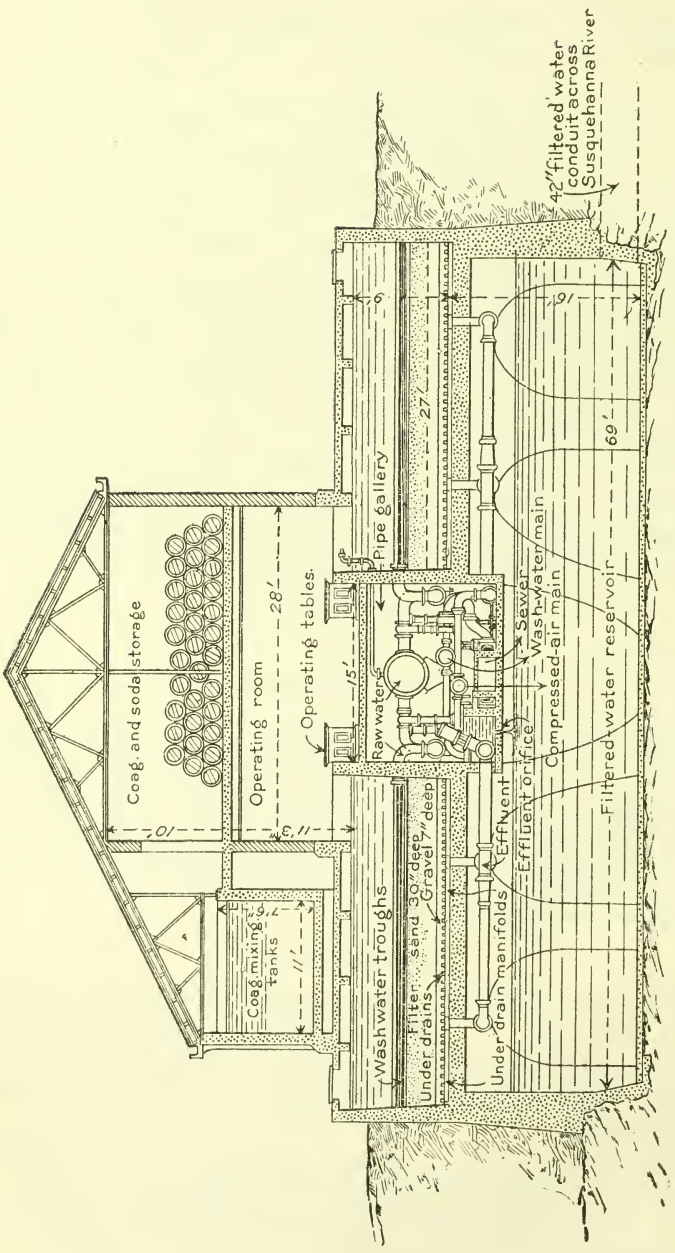


FIGURE 1.—Cross section through filtration plant at Harrisburg, Pa.

per million gallons daily capacity. Without the low-lift pumping station the cost was $164,590, or about $10,300 per million gallons daily capacity.

COLUMBUS, OHIO.

The combined water-softening and filtration works at Columbus, Ohio, were completed in 1906 and have a capacity of 30,000,000 gallons daily. The works are of reenforced concrete, and the buildings are of brick with tile roofs.

The main reaction chamber, wherein the bulk of the softening takes place, is of concrete and is located in the filter building. It is covered and has a capacity of 1,250,000 gallons. The main settling basins, outside the filter buildings, are 12 in number, all uncovered, and are built of concrete. They have a total capacity of 12,000,000 gallons.

The filters, of reenforced concrete built monolithic, are 10 in number, each unit having a capacity of 3,000,000 gallons daily. Each filter tank is 26 feet 2 inches by 46 feet 8 inches by 9 feet 6 inches deep. They are arranged in two rows, between which the pipe gallery is located. The main operating floor covers the pipe gallery, and on it are placed operating tables opposite each filter unit.

The filtered-water basin, built of concrete, is located underneath the filters and the pipe gallery and has a capacity of 10,000,000 gallons.

This plant was built entirely by contract and cost $556,000, a sum which included the softening works, with all of the various devices required for chemical application, and machinery exclusive of all pumping machinery. This outlay corresponds to $18,500 per million gallons. Excluding the cost of the softening works and making an allowance for the extra large settling basins required on account of the softening process, a fair estimate of the cost of the filtration works proper would be $13,000 per million gallons daily capacity.

CINCINNATI, OHIO.

Cincinnati has the largest rapid-filter plant in the world. It was completed in 1907 and has a capacity of 112,000,000 gallons daily. The filters and basins are built of concrete and the buildings of brick. The preliminary settling reservoirs have a total capacity of 330,000,000 gallons, corresponding to a period of sedimentation of nearly three days, when the plant is being operated at its full capacity. From these reservoirs the partly clarified water flows to coagulating basins having a total capacity of 22,000,000 gallons. These basins are so arranged that periods of coagulation may range from half an hour to five hours. The preliminary settling reservoirs and the coagulation basins are earth excavations, lined with concrete and faced with brick and asphalt. They are all uncovered.

The filters, with all appurtenances, coagulant apparatus, storerooms, laboratories, and offices, are located in a brick building with a flat concrete roof. The filter tanks, 28 in number, are divided into four groups of seven each by the pipe gallery. The tanks were built monolithic of reenforced concrete. Each filter unit is 28 by 50 feet in filtering area and has a capacity of 4,000,000 gallons daily.

The filtered-water basin is located outside the filter building and has a capacity of 19,000,000 gallons.

The total cost of the filtration works proper, as outlined above, was $2,681,601, being distributed as follows:

Cost of rapid-filter plant at Cincinnati, Ohio.

	Total.	Per million gallons—	
		Holding capacity.	Filtering capacity.
Preliminary settling basins, open, with piping connections to filters	$1,474,234	$4,467	$13,163
Coagulating basins, open, including piping	331,730	15,080	2,962
Filters, including buildings and piping	724,573	.....	6,468
Filtered-water basins, open, including piping	151,064	7,951	1,349
Total	2,681,601	.....	23,942
Total, exclusive of preliminary settling basins	1,207,367	.....	10,779

LORAIN, OHIO.

The Lorain plant was built in 1907 and has a capacity of 6,000,000 gallons daily. The basins and filters are of concrete and the filter building is of brick with slate roof on steel trusses.

The coagulating basin is located partly under the filters and has a capacity of 580,000 gallons. The filters, six in number, are each 18 by 24.5 feet in filtering area, and each has a capacity of 1,000,000 gallons daily. The filtered-water basin has a capacity of 290,000 gallons.

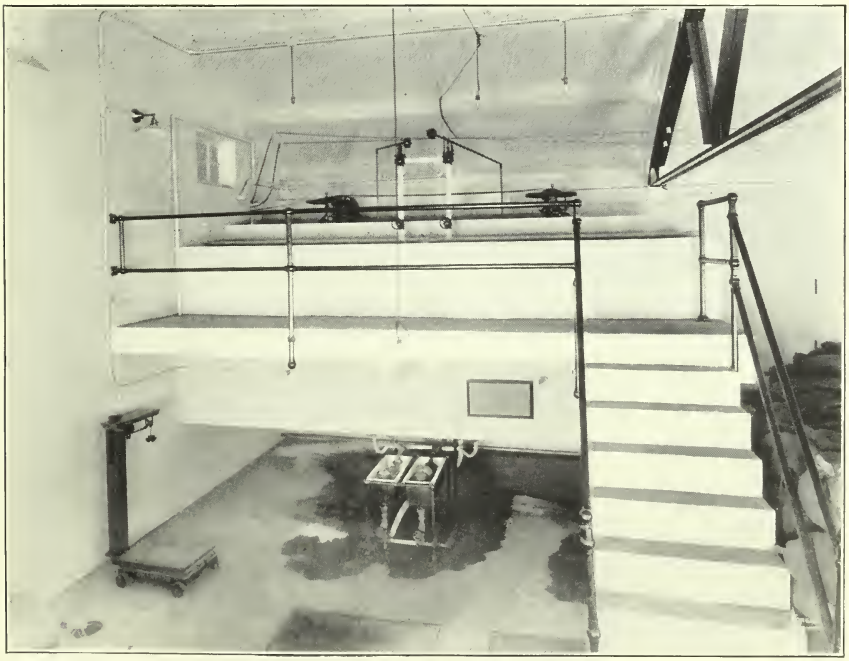
The total cost of the plant, including two low-lift centrifugal pumps, was $85,000, corresponding to about $14,200 per million gallons daily capacity.

SCRANTON, PA.

This rapid sand filtration plant (Pls. V, *B*, p. 42, and VIII), owned by a private company and completed in 1911, was built for the purification of the Providence supply, one of the sources of water supply of the city of Scranton; it has a normal capacity of 6,000,000 gallons daily.

The filtration plant is constructed throughout of reenforced concrete and the superstructure is of brick laid in Flemish bond. The roof is steel trussed and slate covered. The interior finish of the building is in white enamel.

A. WATER AND AIR STORAGE TANKS.



B. COAGULANT STORAGE AND FEEDING DEVICES

CHINCHILLA FILTRATION PLANT, SCRANTON, PA.

Photographs furnished by Scranton Gas & Water Co.

The coagulating basin, in duplicate, is baffled and has a capacity of one to two hours' flow. The coagulant storage tanks are also of reenforced concrete. The clear-water basin is located under the filters and discharges by gravity into Providence Reservoir. The filters are six in number and each has a normal capacity of 1,000,000 gallons a day when operated at 125,000,000 gallons an acre daily. There are two batteries of filters, three on a side, separated by the pipe gallery, which runs the length of the building. The valves are hydraulically operated. Automatic filter controllers of the Weston type are located on the filtered-water outlet of each filter.

The filters are washed by water pressure from an elevated storage tank, and during washing the beds are agitated with air from rotary blowers of the Sturtevant type. The level of wash water in the storage tank is kept practically constant by two Kingsford pattern centrifugal pumps, automatically controlled to start or stop according to the depth of water in the storage tank.

The particular feature which distinguishes this plant from other recent rapid sand filter plants is the manner of cleansing the sand layer. The elevated storage tank for supplying wash water to the filters is not new, but it is a great advantage to have the water level in the storage tank automatically controlled as in this plant, for this insures a uniform pressure of wash water at all times. The aerometer tank for storing air (Pl. VIII, *B*) is a distinct departure in rapid-filter practice, and the results which have attended the use of stored air have been most gratifying. The total cost of this plant was about $80,000.

SUMMARY.

The foregoing examples indicate that unless some unusual features are encountered, like the deep structures at Little Falls or the abnormally large preliminary settling basins at Cincinnati, the cost of a rapid-filter plant, exclusive of high-lift and low-lift pumping equipment, will be about $12,000 for each million gallons daily capacity. On the basis that the water consumption is 125 gallons per capita daily, the first cost to each consumer of such a plant would be about $1.50. At 6 per cent, the interest charges on such an investment would be 9 cents per capita annually.

The above-mentioned fixed charge on the cost of construction of rapid-filter plants is materially lower than that of slow sand filter plants, as would be expected. As a general proposition, it is not usually thought necessary to build large sedimentation reservoirs in which the raw water may be first settled before the coagulating chemical is applied and the water is allowed to flow into relatively small coagulating basins. Where turbid waters are to be purified by slow sand filter plants, large sedimentation reservoirs must be

provided or preliminary filters made a part of the system in order to remove the bulk of suspended matter, which would speedily clog the slow sand filters and make the cost of operation of such filters unnecessarily high. The preliminary treatment factor has a great deal to do with increasing the first cost of construction of slow sand filter plants, and, furthermore, the much greater area of filtering surface required for these filters also explains why it costs so much more to build them. It must be borne in mind, however, that all figures of cost herein given are not to be considered as strictly comparable, but only as examples of what has actually been obtained in the construction in this country of filters of the slow sand and the rapid types.

COST OF OPERATION AND MAINTENANCE OF RAPID SAND FILTERS.

Range of cost.—In the cost of operation of rapid sand filter plants the size of the plant and the quality of the raw water are the main controlling features. Privately owned works are usually operated at lower cost than are those owned by municipalities. As a general proposition, however, the total cost of operation and maintenance of rapid sand filter plants, exclusive of the interest on investment and pumping charges, ranges in this country from about $3 to $5 for each million gallons of filtered water. For some plants the cost is even less than $3, and for others it is in excess of $5 for each million gallons. The following examples will show the cost of operation of several plants in this country.

Little Falls, N. J.—The Little Falls plant is now (1911) filtering about 30,000,000 gallons daily. The charge for superintendence and labor includes the salaries of the superintendent, one filter foreman, four filter attendants, an analyst, and a boy. On a basis of a yield of 30,000,000 gallons daily, the cost of operation for each million gallons of water filtered is as follows:

Cost per million gallons of water filtered at Little Falls, N. J.

Labor	$0.80
Coagulant	1.43
Heat	.35
Power	.22
	2.80

Binghamton, N. Y.—No itemized costs of operation of the plant at Binghamton, N. Y., are available, but it is understood that the total cost is about $6 for each million gallons of water filtered.

Harrisburg, Pa.—During 1910 the Harrisburg filters (fig. 1, p. 58) were operated at an average rate of slightly over 9,000,000 gallons a day. The cost of operation for each million gallons during 1910 was $5.31 and was divided up as follows:

Cost per million gallons of water filtered at Harrisburg, Pa., in 1910.

Labor	$2.52
Coagulant	1.06
Supplies	.28
Repairs	.38
Coal	.63
Oil and waste	.07
Laboratory	.37
	5.31

Cincinnati, Ohio.—During the year 1910, which was a representative year, the average yield of the Cincinnati rapid-filter plant was 49,000,000 gallons daily. The total cost of operation and maintenance was $4.19 for each million gallons of water filtered, this charge being made up as follows:

Cost per million gallons of water filtered at Cincinnati, Ohio, in 1910.

Supervision and attendance	$1.98
Coagulant	1.93
Repairs	.28
	4.19

TOTAL COST OF RAPID SAND FILTRATION.

It has been stated above that the average cost of rapid sand filter plants is about $12,000 for each million gallons daily capacity, which cost will include the necessary filter building, the filters, and the coagulating and filtered-water basins. At 6 per cent this cost corresponds to a fixed charge of about $2 for each million gallons. The addition to this charge of a fairly average figure for operation and maintenance makes the total cost of filtered water by the rapid sand filter system, exclusive of pumping charges, about $6 for each million gallons. On the basis of 125 gallons per capita daily consumption, the total cost of water filtration will be, according to these figures, about 27 cents per capita per annum. This estimate is approximate and is subject to considerable variation according to the conditions in various places. It is obvious that the larger the filter plant the lower will be the cost of operation per million gallons; and also that where waters require a great deal of coagulating chemical the cost of operation will necessarily be increased in proportion.

EFFICIENCY OF FILTRATION.

Slow sand filters will render water clear and practically free from turbidity and will remove a material percentage, probably from 20 to 30 per cent, of the dissolved color in waters stained by decaying vegetable matter. They are not able to treat successfully and economically the very muddy waters of the central western and the southern portions of this country unless such waters are first sub-

jected to long periods of plain sedimentation or to shorter periods if coagulants are used. Rapid sand filters are capable of treating successfully practically all kinds of water, but are particularly applicable to the treatment of waters heavily charged with suspended matter or which are highly colored. The final effluent from such filters will contain practically no residual color or turbidity. Both types of filters will ordinarily remove all but about 1 or 2 per cent of the bacteria originally present in the raw water.

In the following table are given a few representative samples of the efficiency of slow and rapid sand filters in cutting down the typhoid-fever rate in communities where they are used. This is one of the best indices to the bacterial efficiency of filters. In addition to the reduction of typhoid fever effected by filters, it appears to be a fact that the death rate of a community is materially reduced by the substitution of a pure for a polluted water supply. At the International Engineering Congress, held at St. Louis in 1904, Allen Hazen made the following statement:[1]

* * * Where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided. This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water supply, used freely and with confidence, results in a better general tone in the system of the population, and so indirectly to a lower death rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water supply.

Death rate from typhoid fever per 100,000 population in cities using filters.

City.	Kind of filter.	Plant completed.	Years, in average—		Typhoid-fever death rate—	
			Before filtration.	After filtration.	Before filtration.	After filtration.
Albany, N. Y.	Slow	1899	10	10	90	21
Binghamton, N. Y.	Rapid	1902	5	5	47	15
Cincinnati, Ohio	Rapid	1908	4	2	50	13
Columbus, Ohio	Rapid	1908	11	2	78	15
Lawrence, Mass.	Slow	1893	7	15	114	25
Paterson, N. J.	Rapid	1902	5	8	32	10
Pittsburgh, Pa.	Slow	1907	8	3	133	[a] 26
Watertown, N. Y.	Rapid	1904	5	5	100	38
York, Pa.	Rapid	1899	2	8	76	22

[a] Filtered-water section. Allegheny not included.

STERILIZATION OF WATER.

RECENT DEVELOPMENT.

During the last three years (1908–1911) there has been developed a very efficient and entirely harmless method of sterilizing water. The chemical used is hypochlorite of lime or soda, the former being

[1] Trans. Am. Soc. Civil Eng., vol. 54 D, p. 153.

obtained in the form of powder, known commercially as chloride of lime, the latter by electrolyzing solutions of common salt. As early as 1892 the efficiency of hypochlorites as water-sterilizing agents was more or less known, and the subject was studied quite exhaustively on a laboratory scale. Until 1908, however, the use of hypochlorites in the purification of public water supplies had not received serious consideration.

The first practical demonstration in this country of the usefulness of this germicide in connection with water purification was made at the filter plant of the Chicago Stock Yards, on the recommendation and under the direction of the writer, in the fall of 1908. Immediately following the spectacular results obtained at Chicago came the adoption of this process for the sterilization of the water supply of Jersey City, amounting to 40,000,000 gallons per day. The results obtained at these two places were given wide publicity and a large number of scientific articles have since been written setting forth the results obtained with this germicide in different localities and under varying conditions. At this time (1911) scores of cities are making use of it in the purification of their public water supplies, among which are many of the larger cities in North America, including Brooklyn, N. Y.; Cincinnati, Columbus and Toledo, Ohio; Harrisburg, Philadelphia, Erie, and Pittsburgh, Pa.; Hartford, Conn.; Louisville, Ky.; Minneapolis, Minn.; Indianapolis, Ind.; Montreal, Quebec; Hoboken, Jersey City, and Paterson, N. J.; Nashville, Tenn.; and St. Louis, Mo.

THE JERSEY CITY CASE.

Probably the most extended information regarding the hypochlorite treatment in the sterilization of water was obtained in connection with the litigation surrounding the Boonton plant, where the water supply of Jersey City has been treated with hypochlorite since the latter part of 1908. The water supply of Jersey City is derived from Rockaway River, the waters of which are impounded in a large reservoir at Boonton, about 23 miles west of the city. The reservoir has a storage capacity equal to over 200 days' supply at the present rate of consumption, and the water is conveyed from the point of discharge to Jersey City through an aqueduct of concrete tunnel and steel pipe. The sterilization plant is located in the gatehouse and immediately below the dam.

The works are owned by a private company, and several years ago the city raised the contention that the water supplied was not at all times pure and wholesome for drinking, as it was required to be by the terms of the contract. The opinion of the court, handed down May 1, 1908, was to the effect that, owing to certain combinations of circumstances, occurring perhaps two or three times a year, the water

as delivered at Jersey City contained too many bacteria, that sewage bacteria were present, and that on these occasions the water was of doubtful quality. The court did not consider it necessary to filter this water, but held that the company was obliged under the contract to deliver water every day in the year which was free from matter deleterious to health for drinking or for other domestic uses. A sterilization plant was therefore built, being offered as a substitute for sewerage systems and sewage purification works in the communities located on the area tributary to the Boonton reservoir. After many months' operation of this plant, further testimony was heard by the court to determine whether the object sought had been achieved. This testimony, covering about 3,000 pages, was given before a special master in chancery, Hon. William J. Magie, and resulted in the following opinion, rendered May, 1910, which was later confirmed by the chancellor of the State of New Jersey:

> From the proofs taken before me of the constant observations of the effect of this device, I am of the opinion and find that it is an effective process, which destroys in the water the germs the presence of which is deemed to indicate danger, including the pathogenic germs, so that the water after this treatment attains a purity much beyond that attained in water supplies of other municipalities. The reduction and practical elimination of such germs from the water was shown to be substantially continuous.
>
> Upon the proofs before me, I also find that the solution described leaves no deleterious substances in the water. It does produce a slight increase in hardness, but the increase is so slight as in my judgment to be negligible.
>
> I do therefore find and report that this device is capable of rendering the water delivered to Jersey City pure and wholesome for the purposes for which it is intended and is effective in removing from the water those dangerous germs which were deemed by the decree to possibly exist therein at certain times.

HYPOCHLORITE OF LIME.

Hypochlorite of lime, commercially known as bleaching powder, has been and still is extensively used for bleaching in paper mills and many textile industries. It is commonly sold in the form of a white dry powder, and is usually packed in wooden or sheet-iron containers of a capacity ranging from 100 to 750 pounds each. It is manufactured at numerous places in this country as well as abroad, and in large quantities costs about 1⅛ cents a pound at the works.

It is the custom to test the strength of the powder as received by taking a representative sample from the container and subjecting it to what is known as the Penot test, described in Sutton's Volumetric Analysis, ninth edition, page 173. Full details, many of which are taken from this publication, are given at the close of this section.

The chemical in the powder form consists of approximately equal amounts of chloride of calcium and hypochlorite of calcium; when added to water the former salt remains inert, whereas the hypo-

chlorite of calcium, acted on by the free and half-bound carbon dioxide, splits up, with formation of hypochlorous acid. The decomposition of the extremely inert and unstable hypochlorous acid results in the liberation of oxygen in a very active state and of the the chlorine radicle. It is the liberation of oxygen in this way that effects the destruction of bacterial life by oxidation in a manner similar to the result effected when ozone is used.

The general result of the application to water of hypochlorite of lime is the destruction of the majority of the nonspore-bearing forms of bacteria, the oxidation of organic matter in general proportion to the amount of the chemical applied, and a slight increase in the total hardness of the water and in the total solid matter. Where the quantity used is no greater than from 5 to 15 pounds of the powder to each million gallons of water, such as is the common practice, the changes in the physical and chemical characteristics are so slight as to be barely noticeable. The important result and greatest change is the virtual destruction of bacterial life in the water, more particularly the germs of disease-producing origin, including the germs of Asiatic cholera, typhoid fever, etc.

HYPOCHLORITE OF SODA.

Hypochlorite of soda is obtained through the electrolysis of common salt, as already stated. A careful study of the relative efficiency of hypochlorite of lime from the bleaching powder and of hypochlorite of soda electrolytically produced shows that unit for unit hypochlorite of soda is slightly more efficient in the destruction of bacterial life. The process of manufacture of hypochlorite of soda is not so well understood in waterworks circles, however, but it is by no means an intricate process nor one which can not readily and cheaply be installed and operated. It appears certain that where electric current can be obtained for 1½ cents or less per kilowatt hour, and salt for one-third cent a pound or less, it will prove to be a somewhat cheaper germicidal agent than hypochlorite of lime.

Hypochlorite of soda has a number of advantages over hypochlorite of lime. Its use does not call forth the esthetic objections sometimes raised against the use of hypochlorite of lime, as there is no lime sludge to be disposed of. This sludge in hypochlorite of lime solutions contains about as much of the active agent as the solution itself, and can not be dumped indiscriminately into running streams or lakes without danger to fish life or without leaving unsightly deposits on the banks. Furthermore, such deposits have a tendency to clog the orifices in the chemical feeding devices, which does not occur with hypochlorite of soda solutions.

ABSENCE OF POISONOUS FEATURES.

It has been asserted that free chlorine is liberated in the hypochlorite process of water sterilization. In this connection it is well to point out that the term "available chlorine" is one of convenience used by analysts to express the strength of hypochlorite solutions, and was adopted years ago by industrial chemists for the reason that in bleaching operations at some places the commercial product was treated with strong acids which did break up the chemical and release free chlorine. There is abundant evidence to show that the weak carbonic acid found in natural water is incapable of releasing appreciable free chlorine from bleaching powder. Instead, hypochlorous acid, which is not a poison, is produced. Efforts have been made in the past by those who did not favor the process, to find a toxicologist who would classify this treatment as a poisonous one, but all such efforts have failed.

In the Jersey City case Prof. G. A. Hulett, of Princeton University, testified that in his examination of the Jersey City water, to which had been added 10 pounds of hypochlorite of lime to the million gallons of water, he was unable to determine the presence of free chlorine. He stated, however, basing his assumption on the theory of electrolytic dissociation, that it was theoretically possible for free chlorine to be present in the water after such treatment to the extent of 6.4 parts in a trillion parts of water. He admitted that he was unable to prove this assertion. It was furthermore pointed out in this case that if Prof. Hulett's theory was correct, in order for an adult to obtain a medicinal dose of free chlorine, such as occasionally administered to typhoid fever patients as an antiferment and germicide, it would be necessary for such a person to drink over 2,500,000 gallons of water so treated.

PREPARATION OF HYPOCHLORITE SOLUTIONS.

It is the more common practice to make up hypochlorite solutions of 0.5 to 2 per cent strength; that is, 1 to 4 pounds of bleaching powder to 200 pounds of water. It is probable that solutions as strong as 5 per cent may be used without material loss of oxidizing power, but the more dilute the solutions are the easier they are to work with.

For solution tanks concrete or iron appear to be the most suitable materials. Iron tanks last well, owing to protective coatings of lime deposited upon the exposed surfaces. Black iron pipes and special bronze pumps have lasted well in many places. Wooden tanks are the least suitable containers for hypochlorite solutions, but cypress seems to be the best wood if such tanks are to be used. White pine is reduced to a pulp in a comparatively short space of time.

When solutions of hypochlorite of lime are used, it is essential that they be thoroughly stirred in the beginning in order to get into solution all of the soluble parts of the chemical. After that stirring is not absolutely essential, but is convenient for keeping the sludge well distributed; otherwise it gives trouble as the last portion of the solution is removed from the tank. Solutions deteriorate but little on standing, perhaps 2 per cent in a day or two.

PERIOD OF CONTACT OF HYPOCHLORITE.

All of the data available indicate clearly that the germicidal action of hypochlorite is exceedingly rapid. As a general proposition it is thought advisable to provide for a period of contact of about one hour before the water is delivered to the consumer, but the actual period required depends largely upon the character of the water itself. It is also highly important that the chemical be quickly and thoroughly mixed with the water at the time of its application.

AMOUNT OF CHEMICAL USED AND POINT OF APPLICATION.

It appears clear that the best point of application of hypochlorite to a water depends largely on the surrounding conditions. In some places where there are filters it has been found advisable to apply it to the raw water, at others to the water as it flows to the filters. As a general proposition the evidence points strongly to the advisability of applying it to the filtered water. It is essential, however, that there should always be a sufficient period of time elapsing before the treated water is finally delivered to the consumer.

Generally from 5 to 10 pounds of the powder to the million gallons are required to effect practical sterilization of a satisfactorily filtered water. If the water is unfiltered or contains abnormally large quantities of organic matter, or contains dissolved iron, or iron in an incompletely oxidized state, considerably larger quantities of the germicide are required to obtain the best results. Some high-grade filtered waters are satisfactorily sterilized with less than 5 pounds of hypochlorite of lime to the million gallons of water treated and some unfiltered waters require as much as 20 pounds to the million gallons. Each problem must be studied in the light of the surrounding conditions and of data obtained in the very beginning bearing on the capacity of the water for absorbing the hypochlorite under the range of conditions usually encountered during an average year, so that the chemical may effect satisfactory sterilization without leaving behind an objectionable taste.

To aim at the complete sterilization of a water is not necessary. The object to be sought is the destruction of all disease-producing germs, such as those of typhoid fever. This can be done without effect-

ing the destruction of all the bacteria in the water, for the reason that the typhoid bacillus is less hardy than most bacteria which naturally predominate in water and which are known to be nonpathogenic, and their removal, therefore, is not a matter of consequence. Hypochlorite is known to have a selective action on such germs as the bacillus of typhoid fever, and owing to their less resistant state in water it destroys them more quickly and completely. It is not uncommon to find that such bacteria as resist the hypochlorite treatment are spore formers and other hardy forms of nonpathogenic bacteria.

After preliminary study has established the amount of hypochlorite which must be added to a water in order to effect satisfactory sterilization under all conditions, it is the common practice to increase this quantity by about 25 per cent in order to guard against any sudden fluctuations in the character of the unfiltered water which may increase the power of absorption of the hypochlorite. Where the germicide is added to a filtered water such fluctuations are much less marked.

PRECAUTIONS AGAINST UNDERDOSING AND OVERDOSING.

It can be readily understood that if too little of the germicide is used unwarranted security may be caused, and also that for months the results may be thoroughly satisfactory from the use of a given amount of the chemical and that then, owing to a sudden change in the character of the water, unsatisfactory results may be obtained. For this reason it is always better to use more of the chemical than is required under all conditions.

Overdosing, on the other hand, is quite as undesirable. If the attempt is made to sterilize the water completely rather than to destroy the pathogenic bacteria, then there is strong probability that at times there will be imparted to the water a taste or odor which has been variously termed by laymen as similar to that of iodoform or carbolic acid. All of the evidence available seems to indicate that within working limits the presence of a small excess of hypochlorite in the water is not deleterious to health, but it is objectionable to the senses if it produces a noticeable taste, and is therefore inadmissible.

ADVANTAGES AND DISADVANTAGES OF THE PROCESS.

In making a complete analysis of the practicability of the hypochlorite treatment in the sterilization of public water supplies, it is necessary to recognize the fact that its field of accomplishment is limited. Its advantages and disadvantages may be set forth as follows:

1. It will not remove or destroy all of the spore-forming bacteria, but such germs are not considered to be pathogenic, at least those which are common in water. It will not remove bacteria which are contained in particles of suspended matter. It will effect the substantially complete destruction of objectionable bacteria, especially those of disease-producing qualities.

2. It will not remove turbidity nor appreciable amounts of color. nor dissolved vegetable stain, organic matter, swampy tastes, or odors, It will not soften water.

3. It can be reliably and easily applied, and it is not necessary under ordinary conditions to vary the dose, except at infrequent intervals. The cost of the chemical and its application are merely nominal and the speed of reaction makes unnecessary any extensive arrangement as to basins other than for storage. It is difficult of application, except with the greatest care, to waters which contain appreciable quantities of reducing agents or compounds capable of oxidation, such as nitrites and unoxidized iron.

4. The use of hypochlorites is attended by a total absence of poisonous features, either in the chemical product as applied to the water or in any of its resulting decomposition products.

5. It is possible with its use to effect a substantial saving in the cost of coagulation of waters that are of sufficiently unsatisfactory appearance to require clarification or filtration.

6. Its use permits rates of filtration materially in excess of those otherwise possible where high bacterial efficiency is required of the filtration process. It reduces the clogging of the filter beds and consequently lengthens the runs between cleanings. Particularly interesting information as to this line is recorded by Joseph W. Ellms, superintendent of filtration of the Cincinnati waterworks.[1]

These statements set forth the advantages and the limitations of this process, the application of which in water purification problems, though comparatively simple, should always be carried out with much care and fidelity. Otherwise, if the dose is not so adjusted as to meet satisfactorily all the local conditions, there is liable to be alternately an underdose of the chemical insufficient to sterilize or an overdose which will result in objectionable tastes and odors readily noticeable to the consumers and due to the chemical itself.

The use of hypochlorites can not be considered as a substitute for filtration. Where waters are uniformly satisfactory in appearance but open to suspicion as regards their content of bacteria, the use of the hypochlorite process alone may commonly prove sufficient. Where waters are unsatisfactory in physical appearance and are also polluted and require filtration, the combined use of filters and the

[1] Eng. Record, April 8, 1911, p. 388.

hypochlorite process is called for. As an adjunct to filtration processes it has a distinct field of applicability, for at a moderate cost it insures a water above suspicion. Furthermore, there is brought about a considerable decrease in the first cost of the filtration plant. This is made possible by the use of higher rates of filtration, and the required filter area may therefore be reduced. It also effects a substantial economy in the cost of operation.

SOLUTIONS REQUIRED FOR TESTING BLEACHING POWDER.

The following notes may guide the operator in making the simple laboratory tests which are necessary in the hypochlorite treatment:

The solutions required to test the strength of bleaching powder are iodine, alkaline arsenite, with a starch solution used as an indicator.

Tenth-normal iodine solution.—Of chemically pure iodine take 12.7 grams and 18 grams of pure potassium iodide, free from iodate. Dissolve together in about 25 cubic centimeters of distilled water and dilute to a liter. The flask must not be heated in order to promote solution, or iodine vapors would be lost in the operation.

The iodine solution is best preserved in stoppered bottles, kept cool in the dark, and completely filled.

The iodine solution may be verified by titration against a tenth-normal solution of alkaline arsenite.

Tenth-normal alkaline arsenite solution.—The solution of alkaline arsenite is prepared by dissolving 4.95 grams of the purest sublimed arsenious oxide reduced to powder in about 250 cubic centimeters of distilled water in a flask, with about 20 grams of pure sodium carbonate.

The mixture needs warming and shaking for some time in order to complete the solution; when this is accomplished it is diluted somewhat, cooled, then made up to a liter.

In order to test this solution, 20 cubic centimeters are put into a beaker with a little starch indicator, and the iodine solution is allowed to flow in from a burette, graduated to tenths of a cubic centimeter, until the blue color appears. If exactly 20 cubic centimeters are required, the solution is strictly decinormal; if otherwise, the necessary factor must be found for converting it to that strength.

Starch indicator.—One part of clean potato starch or arrowroot is first mixed smoothly with cold water into emulsions and then gradually poured into about 150 or 200 times its weight of boiling water; the boiling is continued for a few minutes; then the solution is allowed to stand and settle thoroughly. Nothing but the clear solution is to be used as the indicator, of which only a few drops are necessary. The solution may be preserved for some time by adding a few drops of chloroform and shaking well in a stoppered bottle, but it is preferable to use a fresh solution each time.

TEST FOR STRENGTH OF BLEACHING POWDER.

The test for strength of the bleaching powder is best made according to the Penot method, as follows: The sample is well and quickly mixed; 7.17 grams are weighed and put into a mortar; a little water is added, and the mixture is rubbed to a smooth cream; more water is then stirred in with the pestle, allowed to settle a little while, and then poured off into a liter flask; the sediment is again rubbed with water, and poured off, and so on repeatedly, until the whole of the sample has been conveyed into the flask without loss, and the mortar has been washed quite clean. The flask is then filled to the mark with water and well shaken; 50 cubic centimeters of the milky liquid are taken out with a pipette and emptied into a beaker; and the N/10 arsenious solution is delivered in from a burette until a drop of the mixture taken out with a glass rod and brought in contact with prepared starch paper gives no blue stain.

The starch paper may be dispensed with by adding arsenious solution in excess and then starch, and then by titrating residually with N/10 iodine till the blue color appears. The number of cubic centimeters of arsenious acid solution used shows the direct percentage of available chlorine.

PREPARATION OF BLEACHING-POWDER SOLUTIONS.

In most of the work done up to this time it has been the custom to prepare solutions of the bleaching powder of about 0.5 to 2 per cent strength, by dissolving 5 to 20 pounds of the dry powder in 1,000 pounds (120 gallons) of water. The solution, after being well stirred, is sampled and this sample is subjected to the Penot test, as follows: Ten cubic centimeters of the solution of bleaching powder are placed in a beaker and N/10 arsenious solution is run in slowly, the contents being stirred continuously with a glass rod. At frequent intervals a drop of the solution is removed on the glass rod and brought into contact with the prepared starch paper. When no blue color is produced on the paper in this way the burette is read and the strength of the solution is figured as follows: On the assumption that—10 cubic centimeters of the solution of bleaching powder are used for titration, that 5 cubic centimeters of N/10 solution of alkaline arsenite solution are used up, and that 1 cubic centimeter of this N/10 alkaline arsenite solution equals 0.003545 gram chlorine; then—

$$5 \text{ cubic centimeters} \times 0.003545 \times 100 = 1.7725 \text{ grams of chlorine per liter.}$$

One liter weighs 1,000 grams, therefore the solution is 0.17725 per cent strong in available chlorine; also each cubic foot of the solution weighs about 28,500 grams, therefore, according to the assumption,

1 cubic foot will contain 50.5 grams (778 grains) of available chlorine. Where 10 pounds of bleaching powder corresponding to 35.45 per cent strength (as above) or 3.545 pounds of available chlorine, are applied to each million gallons of water, it follows that 30.6 cubic feet of such a solution as the above (0.5 per cent in bleaching powder) must be added during each 24 hours, for the reason that 3.545 pounds of available chlorine times 7,000 = 23,815 grains.

Each cubic foot of the solution contains 778 grains, then—

$$\frac{23,815}{778} = 30.61 \text{ cubic feet of solution.}$$

Such a dose of the chemical is equal to 10 pounds of the bleaching powder per million gallons; 3.545 pounds of available chlorine per million gallons; 0.788 pound of available oxygen per million gallons; 0.0238 grain per gallon of available chlorine; 0.407 part per million of available chlorine; 0.091 part per million of available oxygen.

The test may also be made by running in an excess of arsenite solution, adding starch, and titrating back with the iodine solution, as described above in the test for the strength of the powder.

MUNICIPAL WATER SOFTENING.

HARD-WATER SUPPLIES.

Hard waters—those containing high quantities of lime and magnesia in a dissolved state—are less desirable for domestic and industrial use than soft waters. Hard water produces scale in boilers, wastes coal, and shortens the life of the boiler. It is ill suited to the needs of many industries, particularly those in which chemicals are used, such as paper mills. Hard water wastes soap in the laundry and frequently makes necessary the use of washing soda or other compounds which have an injurious effect on some fabrics. It almost always affects the skin unpleasantly, and is more or less undesirable and uneconomical in various ways for general household use.

Waters which have a total hardness of over 50 parts per million (3 grains per gallon) are usually classed among the hard waters. Such waters as these are found in scores of cities in this country, particularly in regions where limestone deposits predominate. To illustrate this point a few examples are given of some of the hardest water supplies of this country. This is, of course, a very incomplete list, and could be added to almost indefinitely. The figures given for total hardness are necessarily approximate, for the hardness of a water naturally fluctuates widely during the year, becoming greater during the months of low stream flow and least during high-water periods.

Approximate total hardness of the raw-water supplies of some American cities.

	Parts per million.
Warren, Ohio	580
Shreveport, La	360
McKeesport, Pa	300
Dayton, Ohio	290
Columbus, Ohio	275
Toledo, Ohio	200
Oswego, N. Y	190
Philadelphia, Pa	180
Starke, Fla	165
Vincennes, Ind	165
Minneapolis, Minn	160
St. Paul, Minn	150
Lancaster, Pa	120
Quincy, Ill	105
Washington, D. C	100
New Orleans, La	95

Water softening is not widely practiced in America except by private industries. Among the cities where the public supply is softened may be mentioned Freeport, Ill., Oberlin, Ohio, St. Louis, Mo., McKeesport, Pa., New Orleans, La., and Columbus, Ohio, the municipal water-softening plant at Columbus, first placed in operation in the fall of 1908, being the largest and the most complete. For complete details of the chemistry of the water-softening problem at Columbus, the reader is referred to an article by A. E. Kimberly, published in the supplement to the Journal of Infectious Diseases, May, 1909.

DISSOLVED MINERAL CONSTITUENTS.

In problems of water softening, the most important features requiring thorough and reliable data are particularly the nature and the relative amount of the dissolved mineral constituents to the presence of which the water owes its hardness. Such data indicate, in large measure, the treatment of the water best adapted to its softening. With rare exceptions the hardness of water is due to the presence of calcium and magnesium radicles.

There are two kinds of hardness, temporary and permanent. Waters in which carbonate or bicarbonate radicles are equal or greater in reacting value than the calcium and magnesium may be almost completely softened by boiling and their hardness is known as temporary. Waters in which carbonate and bicarbonate radicles are less in reacting value than the calcium and magnesium can not be effectively softened by boiling. The removal of all the calcium and magnesium from such water can be effected only by the addition of chemicals that will cause the formation of insoluble calcium and magnesium compounds. Hardness corresponding to the excess in

reacting value of calcium and magnesium over carbonate and bicarbonate radicles is termed permanent.

LIME AND SODA ASH AS SOFTENING AGENTS.

The process of softening water consists primarily in removing from it the calcium and magnesium radicles. This is accomplished with lime and soda ash by the formation of insoluble compounds of these radicles, but these chemicals also react with other substances in the water. The lime is introduced as calcium hydroxide and the soda ash as sodium carbonate. The effects are:

(1) Hydrogen (acidity) is neutralized, forming water; (2) carbon dioxide is changed to carbonate radicle and water; (3) bicarbonate is changed to carbonate radicle and water; (4) iron, aluminum, and magnesium form their insoluble hydroxides and fall as precipitates; (5) calcium present in the water and added as lime is precipitated as calcium carbonate; (6) the sodium of the added soda ash remains in solution in the water.

From the foregoing it appears that lime must be added in quantity sufficient to provide hydroxyl (OH) to combine with the iron, aluminum, magnesium, bicarbonate, and hydrogen radicles, and carbon dioxide. Moreover, if the carbonate radicle in the water plus that formed by the change of the bicarbonate radicle and carbon dioxide is not sufficient to precipitate the calcium present in the water and added as lime, a larger quantity must be provided by the addition of soda ash in order that all the calcium may be precipitated. This latter consideration determines the amount of soda ash to be added. In terms of pounds of 90 per cent lime (CaO) and 95 per cent soda ash (Na_2CO_3) per 1,000 gallons of water, these statements may be expressed in the following formulas:[1]

1. Lime required:

$$= 0.26(rFe + rAl + rMg + rH + rHCO_3 + 0.0454CO_2)$$
$$= 0.00931\ Fe + 0.0288Al + 0.0214Mg + 0.258H + 0.00426HCO_3 + 0.0118CO_2.$$

2. Soda ash required:[2]

$$= 0.465(rFe + rAl + rCa + rMg + rH - rCO_3 - rHCO_3)$$
$$= 0.0167Fe + 0.0515Al + 0.0232Ca + 0.0382Mg + 0.462H - 0.0155CO_3 - 0.00763HCO_3.$$

The formulas may usually be simplified for practical use by the omission of iron, aluminum, and hydrogen, for they are not often

[1] The symbols of the radicles represent the number of parts per million of the various radicles, respectively, found by analysis. The symbol "r" represents the "reaction coefficient." The indicated product represents reacting value in parts per million. Thus, rMg represents the reacting value, in parts per million, of the proportion of magnesium found by analysis. See Stabler, Herman, The industrial application of water analyses: Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 167.

[2] A negative value for this formula indicates that the water has no permanent hardness and that the use of soda ash is unnecessary.

present in sufficient quantity to affect the results. Total incrustants in parts per million (as determined by the standard method of the American Public Health Association) multiplied by 0.0093 will be practically equal to the value of formula 2.

MANUFACTURE OF LIME.

The raw material for the manufacture of lime is carbonate of lime, either as a natural limestone or in the form of the shells of mollusks. By subjecting the raw material to a temperature of 900° to 1,000° C., the carbonic acid is driven off and calcium oxide or quicklime is left.

There are two distinct types of furnace in use for the manufacture of lime, namely, periodic and continuous kilns. In the continuous system the kilns, once charged with alternate layers of limestone and fuel, are never allowed to cool down, resulting in great economy of heat. In this country more lime is perhaps burnt in kilns operated periodically. In this system the charged kiln, after the burning, is allowed to cool down, the lime is removed, and the kiln is recharged and reheated for the following run. In comparison with the continuous system, the periodic method of operation is uneconomical, owing to the losses involved in fuel and in time.

As the result of the burning a good limestone is broken into lumps; it suffers no change in volume, its weight and properties only being affected. The loss of weight during the decarbonization is about 50 per cent. Well-burnt and entirely satisfactory lime should be porous, nearly as hard as the original limestone, and should contain little, if any, magnesium and but inappreciable quantities of silica and iron. For softening water, economy and expediency demand that the highest grade of lime obtainable should be used. It is evident that for softening water the value of a given lime is dependent on the amount of available calcium oxide it contains. As lime is bought and sold on this basis for softening water, the chemical analysis should be the standard under all circumstances.

MANUFACTURE OF SODA ASH.

The manufacturing process of soda ash depends on the fact that bicarbonate of soda is insoluble in ammoniacal solutions of common salt. Common salt, ammonia gas, and carbonic acid gas constitute the raw materials. Strong brine saturated with ammonia is pumped to the top of carbonating towers and allowed to descend through iron baffle plates up through which a stream of carbonic acid is constantly flowing. Under these conditions bicarbonate of soda is formed and separates out, falling to the bottom of the tower, whence it is removed. The crude product is subsequently calcined, carbonic acid and water are driven off, and the pure normal carbonate of soda or soda ash is left.

Soda ash of a high degree of purity may be obtained in the market, and such soda ash alone should be used in all water-softening plants. The percentage of soda ash will vary from 95 to 98 per cent.

COST OF LIME AND SODA ASH.

The cost of high-grade lime and soda ash is subject to considerable fluctuation. Speaking generally, a high-grade lime, containing 90 per cent available calcium oxide or more, may be obtained for about $4.50 a ton in bulk in carload lots. Soda ash, containing upward of 95 per cent sodium carbonate, may be obtained in bags of 300 pounds each for about $20, or somewhat less, a ton in carload lots.

PREPARATION OF LIME SOLUTION.

It may be stated, practically without reservation, that it is advisable to use limewater for softening water. The reason for this is that limewater, being a true solution, is much more readily applied in uniform quantities than milk of lime. In water-softening plants which are operated on an intermittent basis it is possible to make use of milk of lime, owing to the fact that the application of the desired amounts of chemical may be kept under strict control. In plants which are operated on a continuous basis it is obvious that the effect of errors relating to the faulty application of lime must in a great measure vary inversely with the amount of water to be treated, or, in other words, with the amount of chemical to be used.

Although it is true that milk of lime is used in a small number of continuously operated water-softening machines of considerable size, the agitation factor is more particularly emphasized in such apparatus than would perhaps be feasible in larger plants. Without adequate mixing of the raw water and the milk of lime there is a marked loss in softening efficiency on the part of concentrated suspensions of lime, owing to the fact that the suspended particles of calcium oxide become coated over with the precipitating carbonate of lime and hydrate of magnesium, and thereby become inactive. With vigorous agitation this vitiating factor—the inactivity of a part of the lime suspensions—is greatly diminished, but doubtless it is still to be considered as important in proportion to the amount of suspended calcium oxide which the milk of lime contains.

From the evidence available it appears to be clear that limewater possesses distinct advantages over milk of lime in continuously operated water-softening plants for two reasons—first, because of the relative ease with which accurate and uniform application of this chemical may be maintained when it is applied in solution, and, second, because the softening efficiency of limewater is relatively higher. This second consideration involves questions of cost, which must be considered.

In a system of water softening operated on the continuous plan the device in which limewater is prepared is an important feature. In practice limewater is generally produced by diverting a portion of the raw water to the bottom of a tank or reservoir, sometimes known as the lime saturator, where it meets a continuous flow of cream of lime in slight excess of the quantity necessary to soften the raw water and to produce a saturated limewater. Thorough mixing of the cream of lime and the raw water is obtained by means of a stirring device situated at the bottom of the lime saturator. The raw water, softened to the fullest extent possible by treatment with cream of lime alone, becomes a saturated solution of lime. In order to obtain limewater which shall be practically free from undissolved lime and the precipitated salts of lime and magnesium the saturator is made sufficiently deep so that, as the water passes upward to the outlet at the top of the tank, the suspended matter will largely subside.

PREPARATION OF SODA-ASH SOLUTION.

Available evidence indicates that a 20 per cent solution of soda ash in hot water should be used. Such a solution has a specific gravity of 1.23. A solution of approximately this composition is made by dissolving 20 pounds of soda ash in 100 pounds of water.

LIMITATIONS IN WATER SOFTENING.

When once raw water, charged with carbon dioxide, has in its course over or through the earth become impregnated with calcium and magnesium there is no practical process applicable to municipal use which can restore the water to its pristine condition. The reactions and the resulting precipitation will vary in completeness with conditions of temperature, mixing, and sedimentation. Furthermore, the precipitates formed are not wholly insoluble. In a water softened under ideal conditions there may remain in solution 5.2 parts per million of calcium and 3.4 parts per million of magnesium, together with equivalent amounts of negative radicles, representing an alkalinity of nearly 30 parts per million. These figures may be increased by the presence of other substances, so that it is apparently certain that a water once hard can not be softened in a practical plant to less than 34 to 37 parts of alkalinity per million.

With regard to the permanent hardness, it is not generally thought economical or advisable to remove all of the incrustants. As soda ash, which is used for the removal of these constituents, constitutes one of the chief items of expense in softening a selenitic water, its use should be restricted to the lowest limit commensurate with the benefits to be derived therefrom.

FACTORS INFLUENCING THE SPEED OF SOFTENING REACTIONS.

The process of softening water requires considerable time for its completion. Chief among the factors that influence the rapidity with which the chemical reactions involved in the softening process may take place are the temperature of the water, the thoroughness of the agitation to which the water is subjected following the addition of the softening chemicals, and the maintenance in suspension of the precipitating salts during the period allowed for the reactions to take place.

It is a well-known and accepted fact that the majority of chemical reactions take place with relatively more rapidity as the temperature is increased. Those chemical reactions which are involved in water softening belong distinctly to this class. Cold weather during softening retards the process to such an extent that considerably more time is required for the completion than when the water is at a higher temperature; in extremely cold weather the maximum softening effect is often not obtained.

Even when the amounts of chemicals theoretically necessary for complete softening are applied to a given water, a satisfactory removal of the dissolved calcium and magnesium salts will not be obtained without thorough agitation. The importance of agitation in softening water has long been recognized, the means for effecting this end constituting an important feature in the design of the majority of proprietary water-softening machines.

It is a well-known fact that the presence in suspension of the precipitate previously formed or of that formed in the initial stages of the reaction generally assists materially the completion of the process, its success depending on the removal of dissolved substances by the formation of a precipitate as the result of chemical reactions. In water softening this matter is of particular moment, owing in large measure to the fact that the chemical changes involved are taking place in solutions of a high degree of dilution. The importance of the presence of the suspended precipitates throughout the course of the softening reaction has been recognized for many years, and many water-softening machines have been designed with the view of retaining these precipitates.

Available information indicates clearly that at the beginning of the softening process it is highly advantageous to apply the entire amount of lime required to the major portion but not to the total amount of the raw water to be softened. Mention has already been made of the fact that the maintenance in suspension of the forming precipitates materially accelerates the softening reactions. By overdosing a major portion of the water to be softened, the initial softening reactions are greatly accelerated. The action is particularly marked

in the precipitation of the magnesium, which is much more rapidly and completely removed under the conditions outlined above than would otherwise be the case. Further, the indications are strong that by splitting the flow of water to the reaction chamber, overtreating with lime the major portion at the inlet end of the reaction chamber, and, some time after the application of the soda ash, introducing the minor portion of the raw water, the undesirable factor of residual causticity, true of all water-softening processes, would in a large measure be overcome.

In general, therefore, it may be said that the concentrated action of the total amount of lime on the major portion but not on the total amount of water serves to speed up and to render possible a more complete lime reaction, not only as relates to the removal of magnesium but also to the removal of the calcium.

ELIMINATION OF RESIDUAL CAUSTICITY.

In all processes of softening hard water in which lime or caustic soda are used as softening agents, there is a possibility that the softened product will at times contain an excess of free caustic alkali, owing to the frequent changes in the character of the raw water, or to carelessness or accident in the operation of the plant, or to the method of application of the softening chemicals to the raw water. Another condition instrumental in the production of a caustic effluent is the retarding effect caused by low temperature on the rapidity and completeness of the softening reaction. In systems of water softening where the period allowed for the softening reactions to take place is comparatively short, particularly where such plants are designed to furnish water for drinking, rigid precautions are demanded to overcome the occasional inevitable residual causticity. In some plants the matter is controlled by installing carbonating devices for the purpose of subjecting the softened water to the action of carbon dioxide. If properly distributed in adequate amounts through a water possessing causticity, this gas is effective in overcoming this inadmissible condition.

This process is known as "carbonating," the principle involved being the same in all devices designed to accomplish this end. The features essential to successful carbonating are the uniform rate of application of the gas, and the thoroughness with which it is disseminated through the water. Although the process is without doubt practicable for small water-softening plants, its use in large plants would probably entail too great an expense to justify its installation. Further, aside from the cost, which perhaps might be reduced, it appears that the application of the gas to large volumes of

water would cause great uncertainties in this feature of the plant, which must be under perfect control at all times.

Causticity that the raw water can neutralize is obviously equal to the amount of caustic lime (or caustic soda) required to soften the water. As a substitute for the carbonating devices in use in small water-softening plants, the application to the softened water of a small percentage of raw water may be practiced. It is apparent that the percentage of raw water required for each part of free causticity which may remain in the softened water will be one hundred times the reciprocal of the number of parts of lime (CaO), required to soften the water. In other words, all unchanged caustic alkalinity which the softened water may contain will be neutralized by the addition of a small percentage of raw water, the caustic neutralizing power of which is at a maximum.

SEDIMENTATION OF SOFTENED WATER PRIOR TO FILTRATION.

Where river waters are to be softened, filtration usually follows the softening process. The necessity for the sedimentation of the softened water after the reaction period and prior to its filtration refers to the removal of an economical percentage of the precipitated salts of lime and magnesium, together with the suspended mud, silt, and clay carried by the water at flood seasons. It is clear that it would not be practicable or economical to apply to filters the softened water as it leaves the reaction chamber. As the precipitating salts are purposely held in suspension during the reaction period, the major portion of them passes out with the water as it leaves this chamber. The volume of this precipitate will be so great as probably to preclude the direct application to the filter of the water as it leaves the reaction chamber. Furthermore, at times when the river water carries high amounts of sediment, economy in filter operation demands that a period of sedimentation be allowed to intervene before such water is applied to the filter in order that a substantial removal of the mud, silt, and clay may take place in the settling basins.

For still other reasons it appears advisable to provide for several hours' subsidence as a means for compensating irregularities in the operation of a softening plant, namely, to guard against incomplete softening in the reaction period; to overcome uncertain factors introduced by winter weather, producing retardation of the softening action; to avoid the undesirable effect produced by possible after-reactions, which cause deposition of slow-forming precipitates on valves, boiler-water condensers, and the like, and to remove the esthetic objection introduced by the presence in the water, as delivered to the consumer, of small particles of precipitated lime and magnesium compounds.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 316

GEOLOGY AND WATER RESOURCES

OF A PORTION OF

SOUTH-CENTRAL WASHINGTON

BY

GERALD A. WARING

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GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTH-CENTRAL WASHINGTON.

By Gerald A. Waring.

INTRODUCTION.

EXTENT OF AREA.

The area considered in this report comprises about 5,000 square miles in south-central Washington, including Benton County, the eastern parts of Yakima and Klickitat counties, and the western

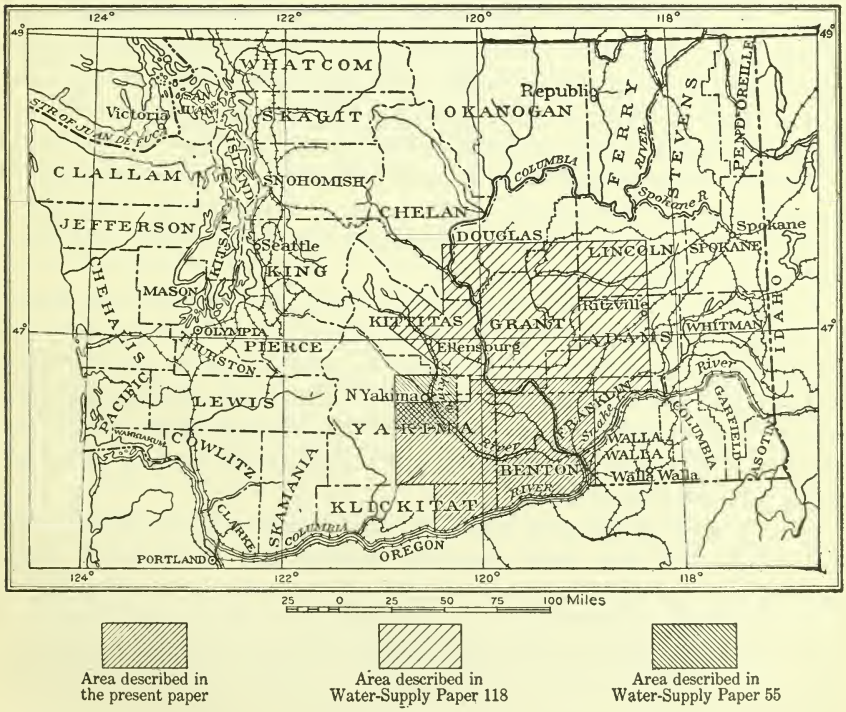

FIGURE 1.—Index map of Washington showing location of area discussed.

part of Franklin County. (See Pl. I and fig. 1.) Columbia River flows southward through its eastern portion and then turns and flows westward, forming the southern boundary of its western portion.

OBJECTS OF THE EXAMINATION.

Until within the last few years the greater part of the region was sparsely settled and was used only as a stock range; recently, however, much of it has been filed upon under the homestead and desert-land laws and is now being rapidly settled and cultivated. Except in the bottoms near the major streams, water is scarce, even for domestic use. In order to study the supply at present in use and the possibility of increasing it by sinking deep wells, the author spent several weeks in reconnaissance during the fall of 1907. The time available permitted only a hurried inquiry into the present utilization of surface and underground water by canals and by wells and a general study of rock characters and structural conditions in their relation to further development of the underground sources.

EARLIER INVESTIGATIONS.

In the summer of 1892 I. C. Russell made a preliminary examination of central and southern Washington with special regard to its water resources, and though more detailed work has led to a modification of some of his conclusions as to the structural conditions in certain parts of the area his deductions as to the underground supply are thought to be generally sound.[1] In his paper Russell states that though shallow water is easily obtained in portions of eastern Washington the region is not a generally artesian area, and that there is little prospect of developing flowing wells in its valleys. In another paper[2] Russell treats of the country to the east, in Walla Walla, Columbia, Garfield, and Asotin counties, describing the wheat lands and discussing the underground water.

A detailed study of the district near North Yakima has been made by George Otis Smith,[3] who describes the main geologic features of the region, the general conditions affecting ground water, and the several streams, and discusses a number of available sites for storage reservoirs. He describes in greater detail the Atanum-Moxee basin, in which North Yakima is situated, and discusses the flowing artesian wells in its eastern portion.

The geology of the area that has been mapped as the Ellensburg quadrangle has also been carefully worked out by Smith.[4] This quadrangle embraces an area of 820 square miles, extending from Atanum Ridge northward to Ellensburg and from North Yakima about 23 miles westward. In addition to treating the rock formations and their structure in detail, Smith discusses the ground waters and the artesian waters.

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[1] Russell, I. C., A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893.

[2] Russell, I. C., A reconnaissance in southeastern Washington: Water-Supply Paper U. S. Geol. Survey No. 4, 1897.

[3] Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901.

[4] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

A general study of the region immediately north of that covered by the present report has been made by Calkins,[1] who gives lists of deep wells in the area around Moses Lake and the cost of drilling them and discusses the possibility of obtaining flowing wells in the several districts. The areas described by Smith and by Calkins are shown on the index map (fig. 1).

As all these publications treat of areas adjacent to that considered in the present report, and as all of them describe regions in which the climatic, geologic, and hydrologic conditions are similar, they have been freely drawn upon. Frequent references have also been made to a recent bulletin of the Department of Agriculture[2] concerning a number of irrigation canals along the lower Yakima River, and to an earlier publication of the same Department on the soils of the Sunnyside Valley.[3]

GEOGRAPHY.

SETTLEMENTS.

The principal towns in the south-central part of Washington are North Yakima, the county seat of Yakima County; Sunnyside, about 35 miles southeast of North Yakima; Prosser, the county seat of Benton County; Kennewick, an agricultural settlement on the western side of the Columbia; and Pasco, a railroad town on the opposite side of the river. By the census of 1910 North Yakima had a population of 14,082, Prosser 1,298, Kennewick 1,219, and Pasco 2,083.

Most portions of the region are easily accessible by rail. The Oregon-Washington Railroad & Navigation Co.'s line follows the south bank of Columbia River from Portland to Wallula, Wash., and there branches eastward to Walla Walla and northeastward to Spokane. From Pasco one branch of the Northern Pacific Railway system follows Yakima River and continues westward to the Puget Sound cities, and another extends northeastward to Spokane. A third line, the Spokane, Portland & Seattle Railway, has been built along the north side of Columbia River into the southern part of the region. Small steamers ply daily along the Columbia, going as far upstream as Priest Rapids, but there is room for much improvement in their facilities.

Along the railroad line that follows Yakima River there are shipping depots every few miles and in addition numerous small towns that depend for trade on the grain-raising portion of the Horse

[1] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905.

[2] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1906.

[3] Jensen, C. A., and Olshausen, B. A., Soil survey of the Yakima area, Wash.: Rept. Field Operations Bur. Soils for 1901, U. S. Dept. Agr., 1902.

Heaven country or on the fruit-raising and dairying settlements farther north. The railroad towns east of Columbia River are mainly centers of supply and shipping points for the surrounding grain-producing sections; the interior towns are mail and trading stations for the neighboring ranches.

CLIMATE AND VEGETATION.

The Cascade Range crosses the State in such a way that it shuts off its eastern part from the rain-bearing clouds of the Pacific Ocean and thus divides the State into two distinct climatic provinces. The western province receives abundant and in some places excessive rainfall and has cool summers and mild winters; the eastern province is arid and has hot summers and severe winters.

The precipitation in the eastern province differs greatly from place to place. Its record shows variation with elevation and with distance from the mountains and exhibits also the wide annual variation common to all arid regions. At Moxee Wells, in the Moxee Valley, the mean annual precipitation for the 11 years from 1893 to 1903, inclusive, was 8.9 inches and the mean annual temperature for the same period was 50° F.[1] At three other stations—North Yakima, Sunnyside, and Kennewick—the precipitation in 1905 was respectively 9.06, 6.48, and 2.88 inches, showing a marked decrease of rain and snow southeastward from the mountains. In the western part of the area examined, which includes the country around Bickleton and that at the head of Reservation Valley, the precipitation is greater than at North Yakima, but no records of the rain and snowfall in this western region are available.

Although most of this area is north of latitude 46° the winter is not severe in the valley lands, for they lie at elevations below 1,200 feet and are to some extent protected by the ridges that separate them. Some snow falls on them, but it usually remains only a short time, so that the winter is "open" most years. Although frost may be expected early in the fall and late in the spring it is seldom so severe as to injure the hardy crops.

Pine and other native trees grow on the higher western slopes and scrub oaks on the lower hills at the west end of Reservation Valley, but sagebrush and smaller desert shrubs form the main natural vegetation of the plains. Along Yakima River and the streams that enter it from the west there are cottonwoods, willows, and alders. The banks of the Columbia along that portion of the river that flows through the area here considered are not lined with trees, though in places they bear clumps of willows.

[1] Henry, A. J., Climatology of the United States: Bull. Q, Weather Bureau, U. S. Dept. Agr., 1906, p. 942.

AGRICULTURE.

The irrigated valley lands yield bountiful crops. Forage plants, especially alfalfa, timothy, and clover, are extensively grown; hops and garden vegetables make valuable crops; and the apples, pears, and other fruits raised are noted for their size and quality.

The supply of stream water easily available for irrigating much of the valley land, and the accessibility of the fruit-growing districts to market by rail, eastward to Spokane and other cities and westward to the cities on the Puget Sound, have greatly aided in bringing the country rapidly to the front. Much of the land that lies above irrigation canals has proved valuable for raising wheat by dry farming.

For the last 40 or 50 years some settlement has been in progress along Yakima River and its tributaries, and water from these streams was early diverted to some extent for irrigation, but active development has taken place mainly since the completion of the Northern Pacific Railway through this region in 1883, and the greatest development has taken place within the last 10 years.

GRAZING.

In early days nearly all this region was used as range for cattle and horses. The settlement of much of the valley land has reduced the area available for grazing, but the higher and more rocky portions of the region will probably never be valuable for other purposes, and many head of cattle still range over them. In summer the cattle graze over the higher western lands, but in winter they are usually brought down to the plains and are fed during stormy periods. Considerable open range remains in the west end of Reservation Valley and to the north, on Selah Ridge.

Many sheep are herded in the mountains during the summer and fall and taken into the cultivated valleys and fed from alfalfa stacks in severe weather during the winter. Some farmers allow the sheep to graze on their alfalfa fields for a short time each day, but the pasturage fee received scarcely seems to compensate for the injury done to the fields by the sharp-hoofed animals.

GEOGRAPHIC PROVINCES.

For purposes of examination and description the area may be conveniently divided into four geographic provinces, namely, Sunnyside Valley, which lies between Rattlesnake Ridge and Yakima River;[1] Reservation Valley, which lies west of Yakima River and between

[1] The Zillah sheet of the Topographic Atlas of the United States, issued by the U. S. Geological Survey, covers parts of the Sunnyside and Reservations valleys, on a scale of about 2 miles to the inch. It maps an area 30 minutes in extent in each direction, most of it in Yakima County.

Atanum and Toppenish ridges; Horse Heaven Plateau, which is in the southern part of the area; and Columbia River Plains, which is in the northeastern part of the area.

SUNNYSIDE VALLEY.

Extent.—On the northeast side of Yakima River, below Union Gap, a wide area of cultivable land, known as the Sunnyside Valley, stretches northward to Rattlesnake Ridge and southeastward from Zillah nearly to Prosser. From the river the land rises toward the crest of Rattlesnake Ridge, its grade increasing near the ridge. Although some portions of the otherwise even surface are hummocky or are cut by small drainage channels, the only important feature of relief is Snipes Mountain, a low ridge on the west-central border of the area.

Development.—The greatest development has taken place in the central part of the valley. In the early nineties nearly all of this land was unsettled and covered with sagebrush, but since that time a great part of it has been brought under irrigation and is now in a high state of cultivation. In 1910 Sunnyside, the largest town in the valley, had a population of 1,379; Outlook, Granger, and Grandview are newer and smaller. A branch line of the Northern Pacific Railway extends from Toppenish to Grandview, furnishing a ready outlet for produce.

This section has been developed very rapidly since water from Yakima River was made available for its irrigation by the construction of the Sunnyside Canal. One who enters the cultivated fields and orchards around Sunnyside after riding from Mabton northward across desert land, covered with sagebrush and sandy hummocks, is strikingly impressed with the results of irrigation.

Soils.—Most of the valley is bottomed by the Ellensburg formation, consisting of gravel, sand, and silt, which is overlain in part by alluvium washed from the higher slopes. From the Ellensburg formation and this latter alluvium a fertile soil has been formed.

In 1909 the gullied slopes north of Sunnyside, above the irrigating canal, were but little cultivated, but the slopes of Rattlesnake Ridge, farther east, had been extensively cleared and devoted to wheat raising. Between Sunnyside and Mabton the land, though cultivable, is more uneven and in places more sandy; most of it, however, will probably be brought under cultivation when ditch laterals have been extended through it. On the south side of the river, between Mabton and Prosser, the soil is thinner than it is in the Sunnyside region and is in places absent, basalt forming the surface, so that not all of the lowland in this locality is suitable for tillage.

In 1901 a soil survey of the Yakima and Sunnyside areas was made by the United States Department of Agriculture, and the classes of

soils and their alkaline contents were determined and mapped.[1] The determination showed that alkali was present in objectionable amount at the surface in only a few places. Beneath the low lands, however, alkalies were found in considerable amount, but as they consisted mainly of sulphates they would probably not become troublesome if proper drainage were provided. Since this examination was made, however, alkaline and swampy tracts have been developed in some of the lower parts of the area through saturation of the ground by overirrigation and by seepage from canals, for nearly all the main canals and laterals are unlined. It is manifest that this rise of alkali can be overcome by drainage canals, and in 1907 work was accordingly begun on the construction of a canal extending from a point near Sunnyside southward to Yakima River.

In this region much alfalfa, clover, and timothy hay is grown, which finds a ready market in the cities of Puget Sound. Hops and garden vegetables are also extensively cultivated, and apples, peaches, and other orchard fruits raised in this section are becoming well known throughout the country.

RESERVATION VALLEY.

Extent and character.—West of the Sunnyside Valley, across Yakima River, the wide, nearly level valley land continues in an area between Atanum and Toppenish ridges known as the Reservation Valley. Its western border is marked by hilly slopes cut by ravines into nearly parallel ridges that rise to form higher portions of the Cascade Range. The valley floor is more nearly flat and is less diversified than that of the Sunnyside region, and the ridges on each side rise more abruptly, so that the boundary between valley and slope is more sharply defined. Like the Sunnyside area, it is floored with deposits of the Ellensburg formation, but these do not extend far up the sidehills. Several branches of Toppenish Creek, which drain the slopes west of the valley, unite at its west end and flow along its southern border, joining Yakima River near Alfalfa. As the branches of this creek rise on wooded mountains its flow is fairly constant, but during the summer much of its water is diverted for irrigation in the southern portion of the valley.

Deposits of coarse gravel in different parts of the valley, especially a gravel terrace that extends from north to south through its central part, indicate that Toppenish Creek has shifted its course over the lowland and in places has left deposits of stream wash on the Ellensburg formation.

Development.—Most of the land of the Reservation Valley lies within the Yakima Indian Reservation and has been allotted to the

[1] Jensen, C. A., and Olshausen, B. A., Soil survey of the Yakima area, Wash.; Rept. Field Operations Bur. Soils for 1901, U. S. Dept. Agr., 1902.

Indians in 80-acre tracts. Prior to about 1905 they were not allowed to sell their holdings; many of them, however, leased their land to whites who cared only to get as much as possible from the soil with a minimum expenditure, and who made few improvements, such as fences and buildings. In 1907, however, a ruling permitted each Indian to sell three-quarters of his land in order to obtain funds with which to improve the remainder, so that within a few years the valley will probably become largely settled by whites.

Farming has been carried on mainly along the south side of the valley and in its eastern portion, near Toppenish. Within the drainage basin of the Reservation Valley, but in its northwestern part, above the valley lands, several orchards and hop yards lie along the upper branches of creeks. The soil here is thin, however, being mainly a dark-red residual material derived from the decay of the basalt, and large parts of it are too rocky to be cultivated.

HORSE HEAVEN PLATEAU.

Surface features.—In the southern part of the area examined, between Yakima and Columbia rivers, lies a region known as the Horse Heaven Plateau, from the luxuriant growth of bunch grass that covered its eastern part in early days, before excessive grazing had made the term inappropriate. From the sagebrush slopes of its eastern portion the surface gradually rises northward to the wooded mountains of the Cascade Range. A few main drainage channels trend southward across it to Columbia River, but it contains no perennial streams. The upper courses of Alder and Cottonwood creeks, however, usually carry water throughout the year.

Settlement.—The higher, western portion of the Horse Heaven Plateau, known as the Bickleton region, has been settled longest, the town of Bickleton having been established over 30 years ago. The more hilly slopes back of this town, which stands at an elevation of nearly 3,000 feet, are timbered. The land south and east of Bickleton has for a number of years yielded crops of grain, but it is only since about 1900 that the lower eastern parts of the plateau have been cultivated, and only since 1905 that homesteading has gone on with much rapidity.

Agriculture.—Wheat is the staple crop of the Horse Heaven Plateau. Hardy winter wheats, chiefly the varieties known as Jones's Five and Fortyfold, are those most raised; though Turkey Red and other spring wheats yield well under favorable conditions.

On account of the deficiency in rainfall it is customary to summer fallow half of the land each year, sowing it only in alternate seasons, for by this means a greater amount of moisture is obtained for the crop. In years of plentiful rainfall, however, some farmers plant all their land.

A number of roads lead from the plateau down to the railroad stations at Mabton, Prosser, Kiona, and Badger. During the summer and fall these roads are marked by trailing clouds of dust raised by teams hauling the wheat for 15 miles or more to the railroad for shipment. This long haul adds considerably to the cost of production.

Soils.—The origin of the soil of the Columbia Plains has been the subject of more or less discussion. Some writers have claimed that it is essentially a residual formation;[1] others have held that it is a wind-borne deposit.[2] It seems probable that the soil of some parts of southern Washington is of one origin and that of other parts is of the other or both. The evidence that has been advanced by writers in favor of each mode of formation seems to apply well to the two classes of soil observed in the Horse Heaven region. The soil of the lower lands is a loose, light-brown, sandy loam, seemingly brought by the winds from the Columbia River lowlands and resting on comparatively unaltered basalt; whereas the soil of the higher slopes seems to be residual in origin and to be a product of decay of the immediately underlying rock.

The thickness of the transported soil on the Horse Heaven Plateau is shown in several places were wells have penetrated it, notably in sec. 29, T. 7. N., R. 30 E., where a well drilled by A. H. Richards passed through 117 feet of the material before reaching solid rock. In areas farther west the soil is much thinner, and in many fields near Bickleton it is only a foot or two deep. It also changes from the light-brown loam to a dark-red heavier soil, having in many places a hummocky, "hog wallow" surface, and lies on partly decomposed basalt.

Granitic bowlders scattered over a band of quartz pebbles that crosses the region from northeast to southwest, near Bickleton, suggest either that at one time the Ellensburg formation may have covered portions of the now uplifted region or that glacial action has extended this far east from the summit of the Cascades. The Ellensburg formation outcrops in a comparatively large area on the lower bluffs near Mabton, where it is the source of the light soil that in summer renders the road so dusty.

COLUMBIA RIVER PLAINS.

GENERAL FEATURES.

The wide expanse of country known as the Columbia River Plains lies north of Snake River, extending in part west of Columbia River but lying mainly east of that stream. On the west low plains lie but

[1] Russell, I. C., A reconnaissance in southeastern Washington: Water-Supply Paper U. S. Geol. Survey No. 4, 1897, pp. 57–64.

[2] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905, pp. 45–49.

little above the level of the river, but on the east bluffs appear along the stream and the land rises to form a plateau. In the main the surface of both the higher and the lower plains is only gently undulating, though a few prominent hills and ridges rise above the general level and wide coulees mark the courses of flood-water channels. Perennial streams do not flow in these channels, but the larger ones in the northeastern part of the plains contain a number of lakes.

The greater portion of these plains is used only as a cattle range, but many homesteaders have come into the region since about 1905 and have cleared the land for grain raising.

AREA EAST OF COLUMBIA RIVER.

East of Columbia River parts of the Columbia River Plains are rocky and untillable, but most of the portion lying within a few miles of the river is covered with the Ellensburg formation, which has decomposed to a soil that is fine grained, light, and easily tilled and that yields well when the rainfall is sufficient. Though no analysis of it is at hand it is known to be a limy soil, as calcareous nodules are scattered over its surface.

On the portion of the plateau covered with soil derived from the Ellensburg formation much work has been done in clearing and fencing the land and in raising grain. The season of 1907 was a favorable one in this section as well as in the Horse Heaven country, and the large crop of wheat and the good price received for it gave impetus to the settlement of these more arid plains.

AREA WEST OF COLUMBIA RIVER.

GENERAL CHARACTER.

The eastern portion of the part of the plains region lying between Rattlesnake Ridge and Columbia River is a nearly level sagebrush-covered plain, much of which is susceptible of irrigation by water pumped less than 200 feet from the Columbia. Near the river a part of the land is covered with cobbles and river gravel and is too stony to be cultivable, though a great part of the river wash is overlain by a loose sandy soil. Farther west this soil is finer in texture and grades into the soil along the base of Rattlesnake Ridge and into that derived from the Ellensburg formation near the mouth of the canyon of Cold Creek.

RATTLESNAKE VALLEY.

A narrow east-west valley, lying west of Columbia River on the western edge of the plains region, is known as the Rattlesnake Valley. On the south it is limited by Rattlesnake Ridge and on the north gentler slopes rise to Selah Ridge. A low divide separates it from

the Moxee Valley, but to the east it opens on the plains bordering Columbia River. The west end of this valley has been occupied by a few settlers for a number of years, but, as in most of the plains region, lack of water has kept it mainly a wheat-raising section. During 1907 the land in the eastern, wider part of the valley, which is known as Spring Valley, was filed on and much of it was sown to grain.

COLD CREEK REGION.

During the two or three years prior to 1907 many settlers took up claims along the lower course of Cold Creek, a few miles north of the Rattlesnake Valley, being apparently induced to do so chiefly by the fact that similar land in the Yakima and Sunnyside areas had become very valuable when brought under irrigation. In this area, which is covered mainly by fine-grained deposits of the Ellensburg formation, there is much tillable but arid land, and the newcomers apparently intended to rely on grain raising for several years at least.

PHYSIOGRAPHY.

RELATION OF SURFACE FEATURES AND STRUCTURE.

Two distinct types of surface features exist in south-central Washington; in one the surface conforms to the structure and in the other it is independent. The broad ridges and the wide, flat plains and valleys constitute the first type. Beneath the plains the rock beds lie nearly horizontal, conforming closely to the present surface except that in the valleys the surface has been made more nearly level by deposits of alluvium. On the ridges the steepness of the slopes is determined by the attitude of the rock layers composing them, many slopes conforming closely to the dip of the underlying rocks.

The gorges that have been cut by the streams directly across several of the ridges constitute the second physiographic type, the most striking example being the gorge cut by Yakima River through Atanum Ridge at Union Gap. Farther north, beyond the limits of the area (Pl. I), the Yakima crosses Selah and Umptanum ridges in a similar manner. Another great gorge has been cut through basaltic layers by Columbia River at Sentinel Bluffs, and a much smaller one near the mouth of Alder Creek, on the southern border of the Horse Heaven Plateau. The cutting of these gorges is most satisfactorily explained on the assumption that the courses of the streams were determined before the uplift of the ridges began, and were maintained as the ridges rose. This assumption is further corroborated by the fact that in a number of places the main drainage lines cross the major topographic depressions, instead of following them, as would be expected.

RELIEF.

The northeastern part of the area shown on the reconnaissance map (Pl. I) lies within the wide, rolling, sagebrush-covered region known as the Great Plains of the Columbia. These plains extend northward and eastward to the Okanogan Highlands, a hilly region in the northeastern part of the State, and westward, as an area of gradually rising ridges and valleys, to the Cascade Range. This range extends from north to south through the State somewhat west of its center, rising in the main to elevations of 4,000 to 7,000 feet, though several volcanic peaks attain heights exceeding 10,000 feet. The two most prominent summits, Mounts Rainier and Adams, are visible from nearly all parts of the plains region. In the southern part of the country between Yakima and Columbia rivers lies the higher region known as the Horse Heaven Plateau. This plateau is bounded on the north by a prominent bluff from which the surface slopes gently southward to lower bluffs along Columbia River, on its southern border. On the west its altitude, like that of the lower plains, gradually increases to the timbered slopes of the Cascades. On the south, across Columbia River, the country also rises to a greater height than the plains and it continues as a rolling plateau dissected by deep canyons far southward to the base of the Blue Mountains.

In the western portion of the area two ridges extend from the slopes of the Cascades eastward into the plains. Atanum Ridge, the northern ridge, rises 1,000 or 1,500 feet above the valley land on each side. Its continuity is interrupted by Union Gap, through which Yakima River passes southward, and about 5 miles to the east by a depression that leaves it only about 100 feet above the valley land on the north. Farther east, however, it rises to join a higher and broader ridge, over 3,000 feet high, known as Rattlesnake Ridge.

About 15 miles south of Atanum Ridge a similar long elevation, known as Toppenish Ridge, terminates before it reaches Yakima River, but it apparently reappears on the east side of the stream as a lower ridge known as Snipes Mountain.

DRAINAGE.

COLUMBIA RIVER.

Columbia River, the master stream of the State, flows through the eastern and southern parts of the area. Although its grade in some parts of its course is only 8 inches to the mile, the great volume of water that it carries gives it a considerable current. At Coyote Rapids and at Priest Rapids outcropping basalt beds give it a much steeper grade and a swifter flow, though not enough to prevent river

steamers from ascending Coyote Rapids and proceeding to the foot of Priest Rapids. The annual change in the level of the river is said to be about 17 feet at White Bluffs. Gage readings at Pasco during 1906 showed a change in level of 13.8 feet at that station, the river being highest in the middle of June and lowest about the middle of January.[1] Its principal tributaries are Snake River, which joins it from the east, and Yakima River, which enters it from the west, a few miles above the mouth of the Snake. Along its south side it receives Walla Walla, Umatilla, and Greys rivers, three smaller streams that drain portions of the country south and southeast of the area considered in this paper.

YAKIMA RIVER.

The most useful stream in this region for irrigation is Yakima River, which flows in a general southeasterly course along the western border of the plains. Unlike many streams of arid regions, the Yakima is not subject to many serious floods, for its flow is to a large extent regulated by lakes near its source and by the well-timbered slopes of the Cascade Mountains. Its flow varies between wide limits, however, the maximum discharge at Union Gap having been about 26,250 second-feet in June, 1903, and 14,700 second-feet in June, 1905; and the minimum 820 and 795 second-feet in August to September of the same two years, which were years of unusually high and low stages. Highest water occurs usually during May and June and lowest during September. Much of the summer flow is utilized in irrigation, and during the irrigation season the normal discharge is greatly diminished below the intakes of the ditches.

The principal tributaries along the lower course of Yakima River are Toppenish Creek, which enters it from the Reservation Valley, and Satus Creek, which flows from the gently rising rocky slopes south of Toppenish Ridge. Toppenish Creek has its source in the wooded slopes west of Fort Simcoe and flows for most of its course in a gravelly channel through the flat valley eastward to the Yakima. Satus Creek also rises in the higher western area, but its several branches flow for the greater part of their courses in rocky gorges in the basaltic slope that rises southwestward toward the Cascades. Nearly all the other streams shown on the reconnaissance map (Pl. I) are intermittent and even in winter carry little water. Several of these watercourses are in wide canyons known as coulees, which are considered to be channels that were cut by streams of considerable size during an earlier period of greater stream flow.

[1] Stevens, J. C., Follansbee, Robert, and La Rue, E. C., Surface water supply of the north Pacific coast drainage for 1906: Water-Supply Paper U. S. Geol. Survey No. 214, 1908, p. 19.

GEOLOGY.

STRATIGRAPHY.

The stratigraphy of the region is simple, the entire area being underlain by the Yakima basalt, more than 2,500 feet thick, overlying which in places is the Ellensburg formation. Except for surficial alluvium, wind-borne soil, etc., all the deposits of the region belong to one or the other of these two formations.

YAKIMA BASALT.

All the country traversed during the field work for this report is underlain by basalt that forms a part of the vast series of effusive materials known as the Columbia River basalt. These lavas cover a great part of southern Washington, eastern Oregon, and adjacent parts of Idaho, Nevada, and California. Basalt that belongs to this series underlies nearly all of the southern part of Washington and constitutes the surface material over much of it. In the area covered by the present report it is known as the Yakima basalt, this name having been adopted[1] in preference to the more general name Columbia River basalt,[2] which includes rhyolites, andesites, and basalts of earlier and also of later periods of effusion than the main flows to which the Yakima basalt belongs. The latter has been determined to be of early and middle Miocene age by fossils that have been found in sedimentary beds interbedded with the lavas and exposed along the canyons of Columbia and Snake rivers and in a few other localities. Of the character of this rock, Smith[3] says:

> As seen in Yakima County, the basalt is a black rock, compact and heavy. On the weathered surface it is often of a brownish color, but wherever exposed it is dark, and the appearance of the ridges is dull and somber, unrelieved by even the desert vegetation. In a few places, where the residual soil can be found unmixed with alluvial or other foreign matter, it is of a bright-red color.
>
> The most noticeable feature of the black rock is the columnar parting by which the black sheets of lava are broken up into long colonnades. In some localities these columns are prismatic, with sharp edges and even sides, the prisms being often so regular as to suggest the work of human hands. This parting is the result of contraction or shrinkage of the solidified lava as the rock mass gradually cooled. The presence of these joint cracks is important, because they afford passages for water in a rock relatively impervious. It therefore is interesting to note the presence or absence of the jointing of the basalt where it is exposed, and such observations have their bearing upon the discussion of the course of the underground waters.
>
> The basalt of certain flows has extremely rough and scoriaceous surfaces due to small cellular cavities which were formed by the steam in the molten rock and which greatly alter its appearance. These varieties, which tell so graphically the story of the lava eruptions, are less common than the compact basalt. Fine and coarse tuffs, or so-called ash beds, are found at a few horizons in the basalt series, but such beds are insignificant when compared with the thicker and more common lava sheets.

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[1] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903, p. 3.

[2] Smith, George Otis, Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901, p. 15.

[3] Idem, p. 16.

Base from reconnaissance map, Northern Transcontinental Survey, by R W Gordon
Detail maps by U S Geological Survey and U. S. Reclamation Service

MAP OF SOUTH-CENTRAL WASHINGTON

SHOWING LOCATIONS OF WELLS AND SPRINGS AND APPROXIMATE EXTENT OF GEOLOGIC FORMATIONS

ELLENSBURG FORMATION.

Over a considerable part of the area sedimentary beds of Miocene age were deposited directly upon the basalt in formerly existing lakes. These beds consist of soft shales, sandstones, and conglomerates, together with unconsolidated sand and gravel. The material formerly covered a greater area than it now does, but it has been washed away from much of the higher lands so that on many slopes only thin patches or scattered pebbles remain. On the lower lands this formation is mostly hidden by stream wash, beneath which it is exposed in a few places along streams and irrigation canals. One of its most extensive exposures is in White Bluffs, along the east side of Columbia River, where nearly 600 feet of sediments is to be seen. At the north end of these bluffs Calkins [1] measured a section 225 feet in thickness, consisting of alternating sandstones, sands, and clays. Another extensive exposure of this material along Naches River, measured by Calkins,[2] shows a thickness of 1,569.5 feet. The deposits are of coarser texture than those at White Bluffs, layers of conglomerate being common and a greater amount of tuffaceous material being present. This difference is doubtless due to the fact that the Naches River locality is much nearer to the original source of the material than the White Bluffs locality.

In many localities outside of the main areas now covered by these bedded materials remnants of them persist, and in some places within those areas the sediments are very thin or are in large part obscured by alluvium. Near Kiona River gravel and wind-blown sand conceal the Ellensburg sediments, if any are present. Farther east, in the vicinity of Kennewick and Pasco, the margin of the formation is obscured by the gravel wash of Columbia River. The extent of territory now covered by the Ellensburg formation is therefore indefinite and can be shown only approximately on the map (Pl. I).

The only definite exposure of the Ellensburg seen in the southeastern part of the region is about 2 miles east of Prosser, where a quarry has been opened in a thick-bedded gray pumiceous sandstone. The record of a well at Pasco, given by Russell,[3] shows 72 feet of sand, 200 feet of Ellensburg formation, and 330 feet of lava to the bottom of the well.

The following section of the rocks exposed in sec. 1, T. 9 N., R. 19 E., was measured by Max A. Pishel, who gathered some additional data on the stratigraphy and structure of the rocks in the

[1] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905, pp. 35–36.

[2] Water-Supply Paper U. S. Geol. Survey No. 55, 1901, pp. 17–21; Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

[3] Russell, I. C., A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 39.

Yakima Indian Reservation in 1912 and made some observations that are incorporated in this report:

Section of rocks exposed in sec. 1, T. 9 N., R. 19 E.

	Feet.
Conglomerate; the upper half consists of an equal amount of coarse sand and gravel, the pebbles of which are largely andesites, porphyries, and quartzites; the lower half is largely conglomerate	86
Volcanic ash, in appearance resembling chalk	5
Shale	45±
Basalt	10–15
Shale, sandy near top, with fossil bones; lower part has the appearance of fuller's earth	200
Basalt	2,000+

In a general way this columnar section resembles the one measured in the Naches Valley by F. C. Calkins,[1] but it exhibits marked differences in detail. On the whole, that part of the formation below the basalt sheet and the conglomerate above it appear to increase in thickness toward the south.

The beds of volcanic ash and shale, 200 feet thick, just above the heavy body of basalt compose the lower member of the Ellensburg formation. This member was measured by Mr. Pishel in sec. 26, T. 8 N., R. 20 E., where he found it to be about 175 feet thick, although the contact above and below was somewhat obscured. Good exposures were found in sec. 22, T. 12 N., R. 18 E., and along the Toppenish Ridge from sec. 1, T. 9 N., R. 19 E., eastward, where it almost completely overlaps the ridge and forms its highest points. Thick beds were traced westward from the last-named locality for about 10 miles along the north flank of the ridge, where they outcrop about 700 feet above the valley floor. To the south they can be traced across the Satus Valley to the north flank of Horse Heaven Ridge. The road running from the mouth of Logy Creek south to Bickleton forms practically the western boundary of this lower member of the Ellensburg formation. The sheet of basalt at the top of this member, the outcrops of which have just been discussed, can not be traced into nor connected with the Wenas basalt described in the Ellensburg folio. Nevertheless the conviction remains strong that it is one and the same sheet and is as persistent in its continuity as the shale and volcanic-ash member underneath. In fact, it is this layer which protects these softer sediments from erosion, and wherever one is found the other as a rule is also present. The conglomerate bed above this basalt is fairly persistent, but was measured only in sec. 1, T. 9 N., R. 19 E., where it attains a thickness of 86 feet, inclusive of the irregularly bedded layers of sand and seams of tuff. Good exposures, 20 feet or more in thickness, were noted in

[1] Op. cit, pp. 35–36.

sec. 30, T. 12 N., R. 18 E.; sec. 6, T. 9 N., R. 21 E.; and sec. 18, T. 8 N., R. 22 E. At these outcrops the bed had not the appearance of a local deposit but rather that of an extended bed. Scattered pebbles of the conglomerate were found in a number of places over the east half of the Yakima Indian Reservation. It is Mr. Pishel's opinion that the red quartzite pebbles, so numerous in the neighborhood of Bickleton and 4 miles to the east and west of that place, are remnants of this conglomerate bed, and that this member originally extended over the ridge a few miles to the north. The exposures in this particular field do not reveal the type of rock that lies immediately above the conglomerate, as the outcrops of that part of the Ellensburg formation are rare in the Reservation Valley, but according to the log of a well sunk very near the middle of the valley the beds above this conglomerate consist largely of shale and sandstone. There is very little doubt, therefore, that the rocks discussed above underlie that part of the Reservation Valley extending from White Swan eastward and also the western part of Sunnyside Valley.

SURFICIAL DEPOSITS.

Besides the wide areas of alluvial valley land belts of gravelly land and of fine-grained alluvial deposits lie along the streams. Yakima River for much of its course between Union Gap and Prosser and also near its mouth flows in a wide gravelly channel that in summer is mainly a cobble-covered waste. Along Columbia River similar wide gravelly lowlands are overflowed during high water but are dry and barren for much of the year. On the west side of the Columbia, above the town of White Bluffs, this gravelly flat has a width of a mile or more. Terraces of similar coarse gravel lie farther southwest toward the Gable Hills.

A few bowlders of granitic rock are scattered over the valley alluvium and also over some parts of the higher lands. These bowlders appear to be erratics brought down during the glacial epoch from the mountains that lie to the northwest.

WATER IN FORMATIONS.

The basalt of this region will not yield much water except where it is jointed or porous. Its principal alkali constituents, such as sodium, potassium, and magnesium, are so combined with silicates as to make them almost insoluble. Therefore water encountered in this rock, unless it has percolated through strata from which it derived soluble minerals before it entered the basalt, will probably be comparatively free from alkali. In general, it can be said that neither basalt nor any other igneous rock is a good water carrier.

Shale and similar sediments found at several horizons in the Ellensburg formation consist of more or less consolidated mud. Such shale is very impervious and does not permit the ready passage of water. Sand, on the other hand, will absorb water readily and permit its free percolation and is therefore an excellent water carrier. When a flowing well with heavy pressure ends in fine loose sand, however, much of it will be carried through the pipe and is likely to cut out the well casing in a comparatively short time. The shale and sandstone in the Ellensburg formation consist largely of volcanic material which is easily disintegrated and attacked by solutions, so that water seeping through a sandy shale or fine sandy volcanic ash will leach out the soluble potassium, sodium, and magnesium compounds and thus become alkaline. For that reason the water obtained from wells, especially shallow dug wells, in the Ellensburg formation is more or less alkaline.

Conglomerate or gravel will transmit water freely and consists largely of almost insoluble material which will not contribute much mineral matter to the water.

GEOLOGIC STRUCTURE.

DEFORMATION.

The sheets of lava that cover southern Washington and thousands of square miles to the east and south originally flowed out as nearly horizontal layers. Upon them were deposited the sediments of the Ellensburg formation also in nearly horizontal layers. Since the deposition of the sediments geologic forces have deformed the whole series of rocks, so that they now constitute mountain ridges separated by wide, flat valleys. In southern Washington these ridges for the most part extend eastward from the higher slopes of the Cascade Range.

There are two such long ridges in the area examined—Atanum Ridge and its eastern continuation Rattlesnake Ridge and Toppenish Ridge and its prolongation Snipes Mountain. Southeast of Toppenish Ridge a third and wider uplifted mass forms the Horse Heaven Plateau.

Russell made several trips through southern Oregon, where the rocks are also of effusive origin, belonging to the Columbia River basalt. In that region they have been broken and tilted to form great blocklike ridges with a steep slope on one side and a gentle slope on the other, having what is known as basin-range structure. In his reconnaissance through central Washington, Russell [1] considered that the ridges of that area also had been produced in large part by the faulting and tilting of great blocks. Detailed study in the Ellensburg

[1] Russell, I. C., A reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, pp. 28, 38, 40, 43.

quadrangle,[1] however, has led to the belief that sharp folding into unsymmetrical anticlines, rather than faulting, has produced the form of structure common in southern Washington.

ATANUM AND RATTLESNAKE RIDGES.

The structure of Atanum Ridge has been described by Smith,[2] who speaks of it as a broad arch with a gentle southern slope and a steep northern front. On its north side the dip is nearly vertical, and near Yakima River the beds are overturned for short distances. About 5 miles east of the river the ridge pitches downward to an elevation only about 100 feet above the floor of the Moxee Valley; but farther east it rises again and forms Rattlesnake Ridge. This mountain was considered by Russell to be an uplifted block, faulted along its north side. It seems, however, like the other ridges of this region, to be more probably an unsymmetrical anticline that has a much steeper dip on its north side than on its south side. Its east end swings farther to the southeast, descends to the level of the plains, and affords a low place for the passage of Yakima River a few miles above its mouth; but on the other side of the river the structural feature continues southeastward in low hills that parallel the lower course of the Yakima at the distance of a few miles. North of Rattlesnake Ridge four low isolated ridges, known as the Gable Hills, rise from the level plain. The basalt layers that compose these ridges dip northward at an angle of about 10°. These ridges appear to be the eastern extension of those which form the bluffs near Priest Rapids and to be remnants of a minor fold between Rattlesnake Ridge and Saddle Mountain, which lies north of Columbia River.

TOPPENISH RIDGE AND SNIPES MOUNTAIN.

Toppenish Ridge, called Satas Ridge by Russell,[3] seems also to be an unsymmetrical anticline or, as he terms it, a monoclinal fold. On its north side the steep attitude of the rocks has aided in causing great landslides. Two of these, named by Russell the Simcoe and Toppenish slides, are conspicuous. At the base of the former, which is about 25 miles west of Alfalfa, the débris has been piled up on the plain below and forms typical hummocky landslide topography, in which there are three small lakes. The Toppenish slide, which is near the east end of Toppenish Ridge and is plainly visible from the railroad, has left a great scar on the hillside, but the material has not been piled up at the foot of the slope so conspicuously as at the larger slide.

Snipes Mountain lies on the east side of Yakima River, in line with Toppenish Ridge, and is very probably a continuation of that struc-

[1] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.
[2] Idem, p. 5.
[3] Russell, I. C., A reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 45.

tural feature. It is almost entirely covered with gravel of the Ellensburg formation, which in a quarry near its southeast side dips about 10° S. In places along its crest basalt bowlders indicate the composition of the core of the mountain, and near its west end a slight depression exposes the basaltic core.

HORSE HEAVEN PLATEAU.

The Horse Heaven Plateau, which lies south of Yakima River, between the Columbia and the Yakima, and extends westward to the Cascade Mountains, has the characteristics of a great unsymmetrical anticline, with gentle south and steep northern slope. Along its northern border its edge is in some places slightly upturned, like the edge of a saucer, and in its northwestern part the bluffs on its north face are so steep as to suggest faulting. However, although no reliable northward dips were seen, owing largely perhaps to the covering of soil and talus, the structure as a whole appears to be due to sharp folding rather than to faulting. Still, in hard, much-fractured rock like the basalt of this region, it is often difficult to distinguish between these two types of deformation, and it may be that actual breaking and slipping has taken place along the steeper portions of the scarp in the vicinity of Prosser. The structure as interpreted is shown in the geologic cross section through this plateau and the plains to the north. (See Pl. I.)

Within the Horse Heaven Plateau there are several minor folds, of which perhaps the most important is the shallow syncline that probably determined the course of Glade Creek, a wide coulee-like drainage channel that is dry during the summer throughout most of its length. Cove Creek, in the southwestern part of the plateau, is a similar wide drainage channel that also probably occupies a shallow structural trough. Other dry channels join these two major drainage lines, but most of them seem to be of erosional and not of structural origin and to be the work of streams during an earlier period of greater precipitation and run-off.

Along the right bank of Columbia River, for several miles west of Carley, on the south edge of the plateau, an anticlinal ridge has been uplifted, across which Alder Creek has cut a gorge to the river. A few other minor irregularities mark the surface of the Horse Heaven region, but in the main it is a plateau surface that forms the southern slope of a great unsymmetrical anticline.

COLUMBIA RIVER PLAINS.

West of Columbia River, between the mouth of Yakima River and Priest Rapids, the basalt layers are in general deeply buried beneath the Ellensburg formation, so that the surface presents few features

of relief. The only notable feature of structural origin is the line of ridges west of White Bluffs known as the Gable Hills, which are probably remnants of a minor fold between the anticlinal Rattlesnake Ridge and Saddle Mountain. East of the Columbia the surface rises to a plateau 600 or 800 feet higher than the plains west of the river, but the attitude of the basalts, where they lie beneath the Ellensburg sediments, indicates only slight folding.

GEOLOGIC HISTORY.

During the Tertiary period great outpourings of lava spread over many thousands of square miles in eastern Oregon and Washington and adjacent areas in Idaho and California. These lava flows changed the pre-existing surface, which was probably one of much irregularity, into a great undulating plain. Upon this plain, in undrained depressions, lakes came into existence into which thick deposits of sand and mud, together with volcanic dust and fragmental material, were washed by streams or blown by wind from the surrounding area and were laid down directly upon the lava surface. A period of deformation followed, during which the rocks were more or less folded along lines running in general from east to west by forces that were subsidiary to those which uplifted the Cascade Range. Later the early lakes were drained and the present major features of relief were given to the country. Still later, during the glacial epoch, ice lobes or perhaps drift ice floating in the glacial lakes strewed the region with bowlders of foreign material brought down from the lands to the northwest. That the glacial lakes were not of great extent nor of long duration seems to be shown by the fact that little lacustrine material of later date was deposited upon the earlier lake beds, the glacial bowlders lying directly upon the earlier deposits. Since glacial time, however, the streams have brought down alluvium from the higher lands and have covered much of the earlier sediment in the valleys.

WATER RESOURCES.

SUNNYSIDE VALLEY.

IRRIGATION.

Sunnyside canal.—The Sunnyside canal, by which the Sunnyside Valley is irrigated, is the largest in the State, having a capacity of over 600 second-feet. Under it lie about 64,000 acres of land, about 40,000 of which were irrigated in 1907. The intake of the canal is on the east bank of Yakima River, just below Union Gap. In 1907 the total length of the main trunk canal was about 63 miles and of the Snipes Mountain, Rocky Ford, and other main laterals 210 miles.

The construction of the canal was undertaken in the early nineties by the Northern Pacific, Yakima & Kittitas Irrigation Co. Owing to financial difficulties the canal was purchased by the Washington Irrigation Co., which operated it until it was taken over by the Reclamation Service in 1906. The Government land under the canal is subject to entry under the terms of the homestead act, modified by the reclamation law. Some lands under the canal were in 1907 still controlled by the Washington Irrigation Co. Of the cost of this deeded land S. O. Jayne,[1] of the Department of Agriculture, says:

> The Washington Irrigation Co. formerly owned the odd sections of land under the canal. The land has been sold with water rights for from $35 to $90 per acre. For a number of years, however, the price of most of the land has been $60, while only that near Prosser was held at $90.
>
> Water rights for several years past have sold for $30 per acre, and considerable water has been rented for nonwater-right land at $2.50 per acre per year. There has been a uniform maintenance fee of $1 per acre on nearly all water-right lands, but a few sales were made in the early days of the company with a 50-cent maintenance fee.

Regarding the distribution of water [2] the same author states:

> One hundred and fifty to two hundred diversions are made from the canal. These diversions range in amount from 1 cubic foot per second or less up to 15 or 20 cubic feet per second and supply laterals from a quarter of a mile to 10 or 12 miles long. These laterals in general follow crests or ridges or elevations, roughly at right angles to the main canal. The farms average about 20 acres, and in most instances each farm receives from the laterals an individual delivery of water, for the measurement of which in most cases weir boxes with adjustable gates have been supplied at the company's expense. Many of the laterals in this way supply water to from five to thirty different farms. The Snipes Mountain lateral, over 12 miles in length, with a number of large sublaterals, constitutes a system larger than that of many independent canals of the valley.

Reclamation project.—In the irrigation of the cultivable land in this part of southern Washington the Sunnyside district is a unit in the general plan of the United States Reclamation Service known as the Yakima project. Ample water supply is assured by storage reservoirs on the headwaters of Yakima River and its tributaries, and the Sunnyside canal and its laterals are being improved and extended so as to supply a total area of about 100,000 acres in this subproject. The irrigation of some 10,000 acres of land that lies on the south side of Yakima River, in the neighborhood of Mabton and Prosser, involves the use of an inverted siphon across this stream.

A higher canal has been considered, which would be able to supply much land that lies along the base of Rattlesnake Ridge above the level of the present canal. Later plans, however, have contemplated the establishment of pumping stations that will lift water from the main canal to these higher lands.

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[1] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1907, p. 32.

[2] Idem, p. 45.

UNDERGROUND WATER.

Shallow wells.—Water for domestic use is obtained throughout the Sunnyside district from wells sunk in the Ellensburg formation to a depth usually of only 50 to 60 feet. Water is found at shallower depths, but as it is alkaline the upper water-bearing strata are cased off in the better wells and the deeper water of better quality is tapped. As irrigating water is supplied by the canal, these wells are drawn on only for domestic use.

The remarkable rise in the ground-water level caused by irrigation is shown by the following table showing the level in wells near Sunnyside:

Water level in wells near Sunnyside, Wash.[a]

Well.	Date of digging.	Depth to water when dug.	Depth to water in 1902.
		Feet.	*Feet.*
No. 1	1890	80	5.0
No. 2	1900	90	20.0
No. 3	1899	42	0.0
No. 4	1892	54	4.0
No. 5	1894	50	3.5
No. 6	1893	53	0.0
No. 7	1900	15	1.0
No. 8	1899	40	6.0
No. 9	1898	53	15.0

[a] Jayne, S. O., op. cit., p. 86.

It is said that between 1900 and 1908 the water plane rose in general about 25 feet throughout the Sunnyside Valley.

Artesian conditions.—The possibility of obtaining flowing wells in Sunnyside Valley in lands above the Sunnyside canal has been much discussed locally, and a few attempts have been made to raise funds to sink a test well. In its general features the Sunnyside region resembles the Moxee Valley, which lies about 25 miles northwest of Sunnyside, beyond Rattlesnake Ridge. In the Moxee Valley a number of flowing wells have been obtained in the sedimentary beds of the Ellensburg formation, and have proved of great value for irrigating high lands, and it is argued that flows should also be obtainable in the Sunnyside Valley.

There are, however, a number of important differences between the Moxee and Sunnyside valleys. The Moxee basin has been shown by Smith [1] to have the trough shape essential to artesian structure,[2] and along its sides the beds of the Ellensburg formation seem to have

[1] Smith, George Otis, Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901, pp. 40–42.

[2] Many years ago the term "artesian" was applied only to water under sufficient pressure to yield flowing wells when properly tapped; but of late the word has come to be applied to wells in which the water rises appreciably, whether it flows or not, the term "flowing" being used to designate those wells in which water rises to the surface and overflows.

been so compressed by the uplift of the bordering ridges as to have become nearly impervious to leakage, and hence to prevent the drainage of the underground basin where the edges of the beds are cut by Yakima River. The Ellensburg formation is 1,000 feet or more thick in the locality in which the successful wells have been obtained, but to the east it thins out rapidly. The flowing wells have been obtained where the surface is at an elevation of less than 1,200 feet, and deep borings on the higher slopes of the Moxee basin have not been successful in obtaining artesian flows. The Sunnyside Valley, on the other hand, although a structural basin, is comparatively shallow, and the lower part of the Ellensburg formation, containing the best water-carrying strata, is probably not buried deeply enough to confine the water effectually over the largest part of this valley. Structurally, the portions of the Yakima Valley between Rattlesnake Ridge and the northern border of Horse Heaven Plateau form a great unsymmetrical syncline with a cross fold—Snipes Mountain—a continuation of the Toppenish Ridge anticline, crossing it from east to west just south of Sunnyside. The Toppenish Ridge anticline pitches eastward until it reaches Yakima River, then rises again in the neighborhood of Snipes Mountain. Eastward from that locality it flattens and is lost in the broad bottom of this great unsymmetrical syncline. The rise of this subordinate anticlinal axis in the neighborhood of Snipes Mountain probably means a corresponding rise of the synclinal fold to the north of it. If this is true, a structural basin forming favorable artesian conditions exists from Granger westward. Thus it may be that small flows of artesian water will be obtained in the neighborhood of Outlook. Farther west these conditions apparently become more favorable, so that the part of the Sunnyside Valley in which wells that may possibly flow can be obtained is roughly bounded by straight lines joining the towns of Granger, Zillah, and Outlook. Flowing wells would be of value as a source of pure domestic water in this locality, and as the cost of a test well would be comparatively small, the attempt to obtain better drinking water by such means is thought to be well worth trying.

The Ellensburg formation in the area lying north of the Sunnyside canal is very shallow and dips gently southward, so that it is highly improbable that flowing wells will ever be obtained here. As the water-bearing strata are comparatively thin from Outlook eastward and the rock basin is probably not closed in that direction, it is not to be expected that artesian flows can be obtained there.

South of Snipes Mountain lies the southernmost of the two troughs into which that mountain and Toppenish Ridge divide the main syncline which extends from Rattlesnake Mountain to the Horse Heaven rim. The axis of this fold extends southeastward from the vicinity of Satus, practically paralleling Yakima River. It is not

closed toward the east, but the bottom of the basin rises until above Prosser the basalt emerges from beneath the Ellensburg sediments. Although these conditions are not favorable to the confinement of the deep waters under the pressure necessary to maintain artesian flows, the basin is worth prospecting, as in some parts of the United States local conditions are such that flowing wells are obtained even in open synclinal basins of this character, and it is possible that similar conditions exist here. The possibility of obtaining artesian water is greatest along the bottom of the basin and decreases toward the sides. It is therefore more probable that flowing wells will be struck in a strip of land a mile wide just north of Satus and running southeastward along the north side of Yakima River than elsewhere in this basin.

Thus far flowing water has been found in south-central Washington only in the sands and gravels of the Ellensburg formation; but the question has been raised whether flowing wells might not be obtained from the basaltic rock that underlies these unconsolidated deposits. Few tuffaceous layers that might act as water-bearing beds seem to be interbedded with the basalts, and though it is probably true that water exists in the more porous "honeycombed" portions of the basalt, these more porous beds are believed to be irregular and of uncertain occurrence. Even if water-bearing beds were known to be associated with the basalts that underlie the Sunnyside basin, it is doubtful if flowing wells could be obtained from them, for the syncline is open toward the east, and so probably permits the escape of the deep-seated water in this direction.

Several springs break forth along the slopes of Rattlesnake Ridge and these have led to a popular belief that an abundant supply of water underlies the upper lands. Some of these springs are of surface origin and rise in ravines where seepage water from the surface soil collects. Others are probably supplied by water that collects in local structural folds or in remnants of the Ellensburg formation and breaks out farther down the slopes, wherever escape is possible. A spring that was opened by Mr. Nicolai in November, 1907, near the summit of the ridge, about 10 miles north of Sunnyside, is believed to be of such character. This spring was said to have discharged three-fourths of a second-foot of water at a temperature of 66° F. during the first few weeks after it was opened.

RESERVATION VALLEY.

IRRIGATION.

Toppenish Creek furnished water for some irrigation along its lower course, and three Government canals, constructed by the Indian Office, divert water from Yakima River below Union Gap and irrigated about 40,000 acres on the Yakima Indian Reservation in 1911.

The adequate irrigation of the Reservation Valley, like that of the Sunnyside region, is provided for by a unit in the reclamation project that covers this part of southern Washington, the unit watering the Reservation Valley being known as the Wapato subproject.

UNDERGROUND WATER.

Good water can be obtained at shallow depths throughout Reservation Valley, though as the present settlement lies almost wholly along Toppenish Creek, the domestic supply is obtained directly from this stream. At the only well (No. 18) noted in the valley the water stood 16 feet below the surface in November, 1907.

ARTESIAN WATER.

Water derived from the collecting grounds in the mountains to the west saturates to a large extent the deposits of the Ellensburg formation in the Reservation Valley. This fact is recognized clearly by the ranchers in the western part of the basin, who have attempted to irrigate the area lying along the outcrop of the gravels of the lower part of the Ellensburg formation with water taken out of Toppenish Creek. Here they find it almost impossible to keep water on the land, as it drains away as fast as it is applied.

The Reservation Valley occupies an unsymmetrical synclinal basin whose steep side lies along the Toppenish Ridge. The axis or deepest part of the trough extends from Granger westward and runs about $1\frac{1}{2}$ miles north of and almost parallel with the south edge of the valley. About 15 miles west of Granger it gradually swings northwestward and passes White Swan about a mile to the north. Dips and strikes of the Ellensburg strata observed along the south side of the basin—that is, along the north flank of Toppenish Ridge—vary from 40° to 90°, whereas the steepest dip noted along the south side of Atanum Ridge is 35°. The dips decrease toward the center of the basin and the bottom of the syncline is comparatively flat but has a slight inclination toward the south, so that the water-bearing gravels in the lowest part of the Ellensburg formation are possibly a thousand feet or more below the surface along the south branch of Toppenish Creek in the lower 19 miles of its course.

The area that is most favorable for flowing wells is bounded about as follows: From Granger northwestward almost parallel to Yakima River to the township line 2 miles north of Wapato, thence westward about 5 miles, thence gradually swinging southwestward to a point about 2 miles north of White Swan, thence curving south and southeast toward the center of T. 10 N., R. 17 E., thence east along the south branch of Toppenish Creek past Alfalfa to Yakima River. The limits in the western part of the basin are more uncertain.

In drilling within the area thus described it would be well to drill down to the Yakima basalt. The only way to be sure of reaching the basalt is to continue drilling until 50 feet or more of the igneous rock has been penetrated. This operation may not necessarily be without compensation, as it is possible to obtain flowing water even in basalt. So far as the writer knows, none of the wells heretofore drilled in this area have reached the gravels at the base of the Ellensburg formation, and it would be well for those who obtain only a small flow in the upper part of the Ellensburg to drill deeper, at least far enough to penetrate these coarse basal beds.

The region lying outside of the area above outlined must probably obtain its water supply from nonflowing wells or from irrigation ditches. Water can be reached in shallow wells at less depth along the stream courses than at a distance from them. As the shale of the Ellensburg formation lies very near the surface along the south side of Atanum Ridge north of the basin described, and as recent stream gravels are entirely absent, it is necessary for those who are attempting to develop local supplies in that area to sink wells deep enough to reach the water-carrying stratum of the Ellensburg formation. Some who have tried in vain to get water along this belt and have abandoned the attempt might well resume work with the expectation of striking such a stratum. At any rate, there is a probability of finding water in the gravel immediately above the Yakima basalt.

It may be argued that as Yakima River crosses the rim of the basin just west of Snipes Mountain at points approximating 670 feet above sea level, the artesian basin should be drained at about this level, and that therefore no flowing wells will be possible in the Reservation Valley. However, as the rocks along the side of the fold are very highly inclined, it is not impossible that here, as in the Atanum-Moxee basin, they are so compressed as to be relatively impervious along the south rim of the basin and thus prevent leakage. Another element that may favorably affect the chances of procuring artesian flows in the Reservation Valley is the probability that the porous beds of the Ellensburg formation become finer and less pervious toward the east away from their source in the mountains, so that water which enters freely along upper Toppenish Creek can escape eastward only with difficulty. Under these conditions of decreasing porosity of the aquifers and resulting increasing frictional resistance to percolation, pressures sufficient to give rise to artesian flows will exist, even though the artesian basin is not closed.

According to a report made by J. W. Martin, superintendent of irrigation at the Yakima Indian Reservation, two 4-inch wells sunk during the winter of 1911–12, in secs. 9 and 16, T. 11 N., R. 18 E., to a depth of about 200 feet struck a water stratum which produced small flows under very slight pressure, and an 8-inch well sunk in June,

1912, in sec. 34 of the same township, to a depth of 512 feet, struck a strong flow. The water from the well in sec. 34 is reported to have a slight taste of sulphur and to have a temperature of 68° F. The log of this well is as follows:

Log of flowing well in sec. 34, T. 11 N., R. 18 E.

	Feet.
Top soil	3
Coarse gravel	123
Bowlders	6
Clay	4
Sandstone	15
Bowlders and clay	14
Sandstone	90
Sand	4
Clay	50
Clay and sand	43
Sand	5
Loose shale (soft)	50
Yellow clay	15
Blue shale	40
Hard sandstone	6
Gravel	9
Shale	15
Sand; first small flow	5
Sand rock	6
Sand; second flow, heavier than first	4
Sand rock; gusher	5
	512

HORSE HEAVEN PLATEAU.

IRRIGATION.

Some years ago preliminary surveys were made for a canal that would take water from the upper part of Klickitat River and bring it to the Horse Heaven Plateau. In 1910 the construction of this canal was again being considered, but its excessive cost, owing to the distance which water would have to be brought and to the difficult character of the country to be traversed, and the lack of knowledge concerning the available water supply combine to render it improbable that it will be built. Many settlers who have anticipated the advent of irrigation by filing on land under the proposed canal hope to make a living by grain farming until water is brought in and orchards can be planted. If water can be obtained and applied to the Horse Heaven lands, the climate and soil will make this an excellent fruit-growing region.

DOMESTIC WATER SUPPLY.

General sources.—In the country near Bickleton water is obtained from dug wells, most of which are less than 50 feet in depth, and from deeper drilled wells. Along the ravines and canyons a few springs

issue and in the coulees water is found within a few feet of the surface. Farther east water is much scarcer and less accessible. A few wells that have been drilled in the eastern portion of the plateau obtain a good supply at depths of 300 or 400 feet, but the cost of such a well, with pumping plant and storage tank, is so great that few ranchers can afford the expense.

A few springs rise along the course of Glade Creek and in other main drainage channels, from which many of the new settlers obtain water, but a number of them are obliged to go 15 miles or more to Yakima or Columbia River for their supply. Tank wagons holding 500 or 600 gallons are used almost exclusively in hauling the water. On a few ranches cisterns have been built, in which rain and snow are collected during the winter and stored to help out on the summer requirements. If a rancher has no cistern or other reservoir, he must either buy water from some neighbor who has one, the rate charged being about 75 cents for 1,000 gallons, or must usually go after a tankful every few days. During the harvest season, when many horses must be watered, the hauling of water is a large item of expense.

Springs.—The following springs (see Pl. I) in the Horse Heaven region are deserving of special mention:

At the house of Mr. B. Beckner, about 4 miles northeast of Bickleton, a spring of clear cold water (No. 8, Pl. I), which is essentially of surface origin, yields perhaps 9 or 10 gallons a minute. Its surplus flow forms a duck pond about 25 yards square. It has been bricked around and inclosed in a small spring house.

Cold Spring (No. 12), west of Dot post office, issues from the steep southern bank of the main drainage channel of the locality and flows between 50 and 100 gallons a minute. It has been used mainly as a watering place for cattle and sheep. Like the Beckner spring it seems to be of surface origin and it issues where a water-bearing bed is intersected by the side of the ravine.

McKinley Spring (No. 10) is an important source of supply to a number of the surrounding ranches. It consists of a pit dug and boarded in against a low bank in the wide drainage course of Glade Creek close to the channel. In the fall of 1907 no water was flowing from the reservoir or well thus formed, though a few pools stood in the stream channel near by. The amount collected from the underflow, however, is sufficient to furnish several barrels a day.

Badger Spring (No. 7), on the northeastern edge of the Horse Heaven Plateau, is similar to McKinley Spring in being a place where the underground flow in a ravine is reached. The water is collected in a rock-walled pit about 10 feet deep. The amount supplied during the summer is small.

Wells.—Most of the wells put down in this area are drilled with portable rigs. Although these outfits are not as powerful as the

heavy standard drilling rigs and although they work very slowly in the hard basaltic rock, they are capable of drilling to depths of 1,500 feet or more. The usual diameter of the wells drilled is 6 inches. One or two feet a day is the best progress that can be made in some of the harder portions of the rock.

The following wells, which were the best known at the time of examination, are worthy of special mention:

The Hayden well (No. 31, Pl. I) is one of the wells of largest yield on the plateau. From it a 14-horsepower gasoline engine has pumped between 20,000 and 30,000 gallons a day during the summer, supplying water to most of the surrounding settlers. The well is 6 inches in diameter and was drilled to a depth of 496 feet. Water was struck at about 200 feet, but the main supply is found near the bottom of the well. This lower supply is said to have risen 200 feet above the depth at which it was struck, so that the pumping lift is about 300 feet. Basalt of different degrees of hardness was encountered below the surface layer of soil, the water coming from a honeycombed phase of the rock.

About 1½ miles southeast of the Hayden well there is a well (No. 30) that was drilled at the joint expense of Yakima County and the State to a depth of 630 feet. The water in it stands about 300 feet below the surface. During the summer a 12-horsepower gasoline engine has lifted an average of about 5,000 gallons a day from it.

A third important well (No. 43), which has supplied several ranchers, is that of Louis Anderson, at Horse Heaven post office. The first water was struck at 225 feet in this well, but the yield amounted to only about a barrel an hour. The main supply comes from a depth of 335 feet, and drilling was stopped 15 feet below this depth. During the harvest season fifteen to twenty 500-gallon tanks have been filled from it each day. The water has been pumped by a 5-horsepower engine and by a large windmill.

The Frances well (No. 32) which is 150 feet deep, struck water at about 100 feet. Its yield is greater than a 2-horsepower gasoline engine can exhaust, and it has supplied a few neighbors in addition to the ranch on which it is located, filling seven or eight 500-gallon tanks a day during the summer.

At the east end of the plateau A. H. Richards has drilled a 6-inch well (No. 50) to a depth of 1,100 feet. At 700 feet a small amount of water, estimated at 125 gallons an hour, was struck, but this was lost at 1,100 feet in shell rock (probably laminated basalt). Below the soil layer, which is 117 feet deep at this place, the material penetrated consisted of alternate layers of basalt 40 to 50 feet thick and softer material, possibly tuff.

In F. W. Sanderson's well (No. 54), about 6 miles east of Bickleton, a number of water-bearing layers or seams were encountered in drilling

to a depth of 309 feet. Water was first struck at 45 feet, but a strong supply was not obtained, as a windmill has been able to pump it out. The red honeycombed rock from which the main water supply of this well is thought to come is exposed along the eastern wall of Spring Canyon, about a mile to the west. Water that was struck at a depth of 65 feet in this well is said to have risen within 15 feet of the surface. The well is situated a short distance south of a swale that seems to lie along the axis of a small syncline, and this structural feature possibly accounts for the pressure of the water in the underlying rocks and its consequent rise in the Sanderson well.

None of these wells are cased, as they penetrate solid rock for most of their depth, though in each one layers of "blue clay," probably tuffaceous beds, are said to have been penetrated. In nearly every well water was found in honeycombed basalt.

About 2 miles north of Bluelight a small flowing well (No. 37) is situated on the slope of a small drainage course on the ranch of L. Spencer, some distance above the bottom of Glade Creek coulee. Its depth is 96 feet; between 12 and 93 feet hard rock was penetrated, but the last 3 feet, from which the water comes, is softer. This well has a fountain head of nearly 6 feet, but yields only about 1½ gallons a minute. Little seasonal variation has been noted in its flow. The anomaly of this flowing artesian well on an upland slope seems best accounted for by the facts that to the south the surface rises 200 feet and that the underlying rocks dip toward the well, so that the pressure developed is sufficient to bring the water to the surface at this point. The small flow in comparison to the head of the well suggests that the supply is small or, what is more probable, that most of the water of the rock layer that has been tapped finds its way on downward to the underground drainage of Glade Creek.

Two flowing artesian wells near Carley, close to the border of the Horse Heaven Plateau, perhaps owe their existence to its structure. These wells are situated north of Columbia River, in Artesian Coulee (Carley's coulee), which seems at one time to have been a channel of the Columbia but is apparently silted up, so that the river now flows in a channel just south of a rocky hill. The eastern well (No. 65) was drilled 162 feet deep and 6 inches in diameter and is said to have a fountain head of 90 feet. In 1907 its water was conducted 45 yards through a galvanized pipe to a ditch 6 feet higher than the well. Into this ditch is discharged nearly a cubic foot of water each second, at a temperature of 74° F. This flow was led eastward and irrigated several fields of alfalfa in the coulee.

M. E. Carley has a similar well (No. 66) on his ranch. In it the main flow comes from a depth of 142 feet, though a smaller flow was struck at 128 feet. This well yielded 1½ second-feet during the first four weeks after it was sunk, but the flow lessened to about 1 second-foot. Its fountain head is said to be only about 5 feet.

Both of these flowing wells penetrate only loose gravel, sand, and clay. About halfway between them a well was drilled to a depth of more than 300 feet without striking an artesian flow. Bedrock was not reached even at this depth, but at about 200 feet mud was encountered of so fluid a character that it produced sufficient pressure to crush heavy casing.

About 3 miles east of Mr. Carley's well another unsuccessful well was drilled 420 feet, mainly through rock. Two other wells of less depth have been drilled on the northeastern edge of the coulee; but up to 1907 artesian flows had been obtained in Artesian Coulee only from the two wells first named.

The slopes of the Horse Heaven Plateau are the most evident source for the pressure of the water in Artesian Coulee. It is possible that water seeping down from this region collects in the silted-up river channel under the head requisite to yield the flowing wells. That only two wells have been successful in tapping such a supply indicates that the water-bearing beds are not continuous, but probably exist as lens-shaped masses of sand and gravel, interbedded with mud and clay.

Of the shallow wells in the Horse Heaven region two (Nos. 27 and 48) may be mentioned as typical. The former, the Amond well, dug in a small ravine, supplies only about 400 gallons a day in summer, at which season the water stands about 15 feet below the surface; in winter, however, it rises nearly to the surface. The other well, that of Don Creswell (No. 48), is also in a drainage channel, at a place formerly known as Cottonwood Spring. The group of trees from which the spring received its name still remains, but the well, 35 feet in depth, has seemingly appropriated the water supply. In 1906 this well went dry, but in the fall of 1907 it contained 15 feet of water and supplied 30 horses. Other shallow wells yielding small supplies of seepage ground water have been dug along the same drainage line, both above and below Cottonwood Spring.

Artesian conditions.—The conditions under which flowing artesian water is usually found have been fully discussed in several publications of the Geological Survey,[1] so the subject is not taken up here. The existence of water under sufficient pressure to yield flowing wells in areas that do not contain typical structural artesian basins nor alluvial artesian slopes has been discussed by Fuller,[2] who has cited examples of flowing wells in areas that do not have the usual structure of artesian basins. It is therefore evident that, although the Horse Heaven Plateau is not similar in character to areas in which the best flowing wells are obtained, the existence beneath it of water under

[1] Fuller, M. L., Water-Supply Papers No. 54, pp. 101–104; No. 78, pp. 10–14; No. 118, pp. 61–67; and Bull. No. 319.

[2] Fuller, M. L., Summary of the controlling factors of artesian flows: Bull. U. S. Geol. Survey No. 319, 1908.

sufficient artesian pressure to flow is not impossible; in fact, in nearly all the deep wells drilled in this region the water rose notably above the level at which it was struck. The question has therefore often been raised whether flowing artesian wells can not be obtained by drilling to greater depths. In partial answer to this question it may be said that although water in the underlying vesicular and tuffaceous phases of the basalt is under considerable pressure and rises in deep wells so as to reduce the cost of pumping very materially, in none of the wells does it rise close to the surface. Moreover, a sufficient number of wells have been drilled to show that it is very probable that flowing wells can not be obtained on the plateau. Any that may be developed, like that of Mr. Spencer (No. 37), will be due to an unusual combination of favorable conditions.

COLUMBIA RIVER PLAINS.

AREA EAST OF COLUMBIA RIVER.

The water conditions in the eastern part of the Columbia River Plains are similar to those in the Horse Heaven country. A few springs furnish small supplies, a few deep wells have been drilled in the higher lands, and shallow wells have been successful in obtaining water along the coulees, but a number of settlers haul their supply from Columbia River.

IRRIGATION.

During the fall of 1903 and the spring of 1904 a careful reconnaissance of the southern and eastern parts of Franklin County was made by the United States Reclamation Service in order to determine the feasibility of irrigating the area by water taken from Palouse River. This project contemplated the irrigation of lands between Columbia and Snake rivers and between Connell and Pasco. In 1910 no work beyond the reconnaissance had been done on this project, because of the doubtful feasibility of the construction of the main storage reservoir and the probable high cost per acre of the project, even if it could be successfully completed.

Only one small pumping plant along the Columbia was noticed. This was on a farm on the east bank of the stream a few miles below the mouth of the Yakima, where an engine and centrifugal pump lifted water to irrigate a few acres of alfalfa and garden.

UNDERGROUND WATERS.

On the plateau surrounding Eltopia a number of drilled wells draw domestic water supplies from seams or from honeycombed portions of the underlying basalt. Little ground water is found in the unconsolidated deposits of the Ellensburg formation.

In H. Wysong's well (No. 5) water was struck at a depth of about 340 feet and rose within 100 feet of the surface. About a mile farther

east, in the well belonging to H. Meentz (No. 4), water was struck at 375 feet and rose about 50 feet. About a mile to the west, in Mrs. M. P. Jordan's well (No. 7), the water level is nearly 400 feet below the surface. Near the eastern base of the portion of the plateau which terminates in White Bluffs Joe Allen obtained an abundant supply of water in a well (No. 3) 42 feet deep, sunk into the basalt underlying the gravel of a flood-water channel. In the fall of 1907 Mr. Allen had a 3-horsepower gasoline engine and 3,000-gallon storage tank and supplied several neighbors.

In the lower lands north of Snake River wells dug in the deep gravel of coulees find a small supply of water. The porous character of the dry gravel in these old stream channels tends to produce breathing or blowing wells such as are found in a number of other places in the United States.[1] One such well that was visited (No. 26) is about 4 feet in diameter and 100 feet deep, in the bed of a shallow coulee. Nearly all the material passed through appeared to consist of rather loosely packed subangular pebbles, ranging from 1 to 3 inches in diameter. At the time the well was visited the barometer was falling and a strong current of air was rushing outward through the cracks of the board cover; this outrush continued with apparently undiminished force during the half hour spent at the place.

AREA WEST OF COLUMBIA RIVER.

RATTLESNAKE VALLEY.

Wells.—Several of the earlier settlers in the western part of Rattlesnake Valley put down drilled wells from which they pump water by windmills for irrigating small gardens as well as for domestic use. Information concerning the principal wells is given in the table on pages 44–45. Over most of the valley the soil is thin, as only remnants of the Ellensburg formation are left, and in drilling most of the material passed through is basalt.

Springs.—In the Rattlesnake Valley, as elsewhere through the plains region, the water supply is still derived largely from springs. The principal source of supply is Trough Spring (No. 3), which is situated in a small ravine where apparently an outcropping basalt layer brings ground water to the surface. A covered reservoir has been built in the ravine in which the flow of perhaps 8 or 10 gallons a minute is collected. From this reservoir water is hauled by the settlers in the usual tank wagons.

Several other surface springs issue along the higher slopes on the north side of the valley. In connection with their occurrence it is

[1] Condra, G. E., Geology and water resources of a portion of the Missouri River valley in northeastern Nebraska: Water-Supply Paper U. S. Geol. Survey No. 215, 1908, pp. 31–32.

interesting to note a dug well (No. 10), also on the north side, in which water was reached at a depth of 17 feet. The slope was sufficient to permit the owner to tunnel in from a point 40 or 50 yards down hill from the curb and lay a pipe to the bottom of the well. Thus he obtained flowing water, virtually a surface spring, in his barnyard. Water for the house has been obtained from the same well by wheel and bucket.

Barrel Spring (No. 2), on the northwest edge of Spring Valley, was the main source of supply for the settlers in the locality in the fall of 1907. At this spring, which issues at the base of a low bluff, a barrel had been sunk and the flow of about 5 gallons a minute was piped into two troughs. The overflow filled a small earthen reservoir that was used as a watering place for sheep. During the early part of 1908 O. G. Steward ran a tunnel into the hillside about 200 yards east of this spring and developed a small but constant flow of water. It is probable that in several other places along the sides of the valley water may be obtained from similar tunnels, but it is not likely that springs that will yield enough water for irrigation can be developed.

In the middle part of the course of Rattlesnake Creek, at the edge of the plains, Rattlesnake Spring (No. 1) issues along a steep-sided gully in the alluvium that floors the valley. It forms a stream having a fairly constant flow of 500 or 600 gallons a minute. The spring water is led through a ditch for about 2 miles southeastward to the ranch of E. F. Benson, where it is used to irrigate about 75 acres of alfalfa and 25 acres of potatoes and other garden vegetables. It also supplies domestic and stock needs, for a well is said to have been sunk to a depth of 105 feet at the ranch without striking water.

Two or three other springs that issue along the northern slope of Rattlesnake Ridge are used for irrigating small areas of alfalfa and vegetables.

The existence of these springs has been considered by the residents to indicate artesian conditions. They seem, however, to be more probably of surface origin and to be supplied by the rain and snow that collects on the slopes above. This water seeps down the hillsides and issues at places where fissures in the rocks and the attitude of the beds and their relation to the soil covering furnish favorable conditions. The rocks on the sides of Rattlesnake Valley have been folded and also probably much fractured in the process of uplift, so that many opportunities are given for ground water to reappear along the lower slopes.

COLD CREEK REGION.

Irrigation.—Among the recent settlers in the lands west of the Columbia there has been much talk of the projected Government high-line canal, which is expected to water nearly all of the land lying above the present irrigation works. It is possible to bring

water to most of this arable land by a gravity canal, and in connection with the Yakima project of the Reclamation Service surveys for canals to supply this area have been made. Chiefly on account of the fact that a sufficient water supply is not available from the proposed source, however, the irrigation of these higher and more remote lands has been, at least for the present, abandoned, and attention has been given to the lower areas in Atanum, Reservation, and Sunnyside valleys, along Yakima River, and below Kiona, all of which can be more easily supplied.

The Benton subproject of the Reclamation Service originally contemplated the irrigation of about 210,000 acres in Benton County, of which 180,000 acres lies north of lower Yakima River and 30,000 acres south of that stream. The land south of the river can be reached by siphon. Water is to be diverted from Yakima River near Prosser and conducted by canal around the south end of Rattlesnake Ridge and along its eastern base.

During 1907 two private irrigation companies began the construction of works to irrigate land in the northwestern part of the plains along the Columbia by water pumped from the river into canals. These systems were intended to irrigate about 33,000 acres, cutting down by that amount the original area that was to be covered by the Benton subproject.

It is the intention to make this land along the Columbia mainly a fruit-growing district, as its mild climate and long frostless season are well adapted to this branch of farming.

Underground waters.—Few tests have yet been made for underground water in the plains area west of the Columbia. It is probable, however, that ground water can be obtained at relatively slight depths beneath most of it. In the gravelly land within a few miles of the river abundant water is reported near the surface. At the Hanford Hotel a dug well (No. 2, Pl. I) reached water at 43 feet. The depth of water in this well changes with the height of the river, at about whose level water was reached, and it is probable that seepage from the river supplies the well. About 2 miles south of White Bluffs two dug wells obtained water at a depth of about 90 feet. Near them a drilled well (No. 1) was sunk a few years ago, in search of flowing artesian water, to a depth reported to be about 400 feet. Water was reached at 67 feet, at about the level of the river, but no strata carrying water under pressure were found. The material penetrated below the river gravel was probably the Ellensburg formation, as hard rock was not encountered.

The Ellensburg formation probably underlies much of the gravel that covers the low-lying land west of the river, but there is little chance of finding flowing water in it; for although Rattlesnake Valley and the valley of upper Cold Creek are of synclinal structure

and contain deposits of the Ellensburg formation, they are not so deeply nor so completely filled with this material as is the Moxee basin, in which flowing wells have been obtained. These valleys also open eastward to the broad plains region, beneath which the Ellensburg strata lie nearly horizontal, so that the collection of water in these beds under sufficient pressure to rise to the surface is rendered very improbable.

IRRIGATION ALONG LOWER YAKIMA RIVER.

Besides a number of small canals in the Moxee Valley, the canals of Reservation Valley, and the Sunnyside canal, a number of canals take water from the lower course of Yakima River. The following statements concerning these canals are condensed from a publication of the United States Department of Agriculture.[1]

The uppermost canal receives its supply from the river at Prosser, where the Prosser Falls Land & Irrigation Co. has built a concrete dam across the stream, raising the water level about 10 feet and giving a power head of nearly 12 feet. By means of turbines and cylinder pumps, water is lifted into a canal with two branches, one of which extends 8 miles southwestward along the bench land bordering the river; the other extends 3 miles in the opposite direction; together they supply about 1,300 acres. Water and electric light are also furnished to the town by this plant.

About 4 miles above Kiona, on the north bank of the river, is the intake of a canal that was formerly owned by the Northern Pacific Irrigation Co. In 1907 ownership was transferred to the Kiona Development Co. The canal is 9 or 10 miles long, and between April 1 and November 1 the amount of water carried by it is about 25 second-feet. It irrigates from 1,400 to 1,800 acres, but if it were extended it could be made to supply about 26,000 acres.

A smaller canal, only about 2 miles long, irrigates a few acres across the river from Kiona. This canal is several feet below the level of the fields it irrigates, and water is lifted from it by current wheels. In summer it carries 15 to 20 second-feet, but only a fraction of this amount is available for irrigation.

The Grosscup canal, about 5½ miles in length, takes water from the north bank of Yakima River about 10 miles below Kiona and irrigates a small area on the Grosscup farm.

Just across the river from the heading of the Grosscup canal is the intake of the Kennewick canal, which was constructed in 1894 with a length of over 20 miles. After two years' use it was abandoned, owing to financial difficulties, but later the property was acquired by the present company, the canal was enlarged and reconstructed, and

[1] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1907.

in 1907 it had been in use for five seasons. The main canal is about 35 miles long and carries during the irrigation season between 125 and 150 second-feet. Under it there is about 12,400 acres, about a third of which was irrigated in 1906.

The lowest canal to take water from Yakima River is the Amon canal, owned by the Benton Water Co., which has its intake on the north bank of the river, about 5 miles below the Kennewick and Grosscup canals. It irrigates land near the town of Richland, between Yakima and Columbia rivers. About 2,500 acres of land under the canal and its branches was originally owned by the company.

SUMMARY.

In Sunnyside Valley water for domestic purposes is obtained in part from wells dug to the ground-water level and in part, of a better quality, from bored wells cased to the deeper water-bearing strata. There is a possibility that artesian flows will be obtained north of Snipe Mountain in a triangular area bounded approximately by straight lines joining the towns of Outlook, Granger, and Zillah, this area being a part of the favorable belt that extends westward across the Yakima and occupies a part of the Reservation Valley. Throughout most of the area the Ellensburg formation is so thick that few wells penetrate below it. On the eastern border, where the formation is thinner or entirely lacking, wells must be drilled to considerable depths into the basalt, but they obtain water of good quality. A notable rise of the ground-water level in the lower areas has taken place since the introduction of irrigation.

For irrigation the Sunnyside canal furnishes ample water to the land below it, but there is need of water to irrigate the land above this supply. The possibility of obtaining artesian flows for this purpose is remote. It is probable, however, that before many years a higher canal or pumping stations will be constructed that will bring under irrigation a great part of this cultivable but as yet unwatered land.

In the Reservation Valley the conditions are similar to those in the Sunnyside Valley. Ground water for domestic use is in most places easily obtained from shallow wells, and as it comes from the near-by slopes of the Cascade Mountains it is generally of good quality. The rock structure underlying this valley is such as to form a partly inclosed basin, and it is probable that flowing wells can be obtained in that part of the valley which lies within the following boundaries: From Granger northwestward almost parallel to Yakima River to the township line, 2 miles north of Wapato; thence westward about 5 miles; thence gradually swinging southwestward to a point

about 2 miles north of White Swan; thence swerving south and southeastward toward the center of T. 10 N., R. 17 E.; thence eastward along the south branch of Toppenish Creek past Alfalfa to Yakima River.

Irrigation has not been developed in this valley to the extent that it has across Yakima River, chiefly because the land has been owned by the Indians. The ruling that allows the Indians to dispose of three-quarters of their holdings will probably cause rapid settlement by whites. As most of the land is low-lying, it will nearly all be brought under easy irrigation by the construction of the Reservation canal.

In the southern part of the Columbia River Plains, in the region that lies between Snake and Columbia rivers, the underground water supply has been but slightly developed. In the settled portions near the Columbia this stream is the main source of domestic supply; in sections more remote water is obtained from small springs or wells dug in coulees, and in the higher plateau portion it has been necessary to drill wells to considerable depths.

Irrigation is practiced in a number of areas along lower Yakima and Columbia rivers, but much of the land, though fertile, will probably remain unwatered and be used mainly for raising grain for a number of years to come. Gravity canals from the Columbia seem impracticable, and pumping plants are expensive and are most economically installed in large units. This means that irrigation of these portions of the plains region can not be efficiently undertaken by each farmer for himself but must be undertaken by the State or National Government or by development companies.

The region is, however, endowed with a great supply of water in Yakima and Columbia rivers. Development has already taxed the supply of the Yakima, but proposed storage reservoirs on its headwaters will render available for irrigation much of the winter as well as the summer flow and enable it to supply much more land than it can at present. Along the master stream, the Columbia, development has hardly begun. The river carries an almost limitless supply of water, but its utilization presents serious engineering and economic difficulties. The grade of the river is so slight that long and expensive canals will be required in order to obtain gravity supplies from it, and pumping projects involve expensive machinery and heavy lifts.

Although some of the higher lands will remain grain-raising districts for many years to come, it seems probable that before long the greater part of the lower-lying areas will be brought under canal lines and rendered as productive as similar lands in the Yakima and other highly developed districts.

WELLS AND SPRINGS.

The wells and springs listed in the following tables were visited in the course of the examination of the region. Reference has been made to many of them in the text, but the data are here assembled, together with those on others not previously mentioned, for more convenient use with the map (Pl. I), on which the wells and springs are shown by symbols whose numbering corresponds with that in the lists.

Wells in south-central Washington.

No.[a]	Owner.	Location.			Class of well.	Depth.	Depth to water.	Remarks (depth in feet).
		Sec.	T. N.	R. E.				
						Feet.	*Feet.*	
1	.....	4	13	27	Drilled..	[b] 400	67	Through soft materials.
2	Hanford Hotel.....	25	13	27	Dug.....	45	43	Water at river level.
3	Joe Allen.....	28	13	29	...do....	42	40	In basalt underlying gravel of coulee.
4	H. Meentz.....	25	12	29	Drilled..	407	325	Water at 375.
5	H. Wysong.....	26	12	29	...do....	473	100	Water at about 340. Strata passed through: Sand, 0–20; clay, 20–150; sand 150–160; shale, 160–325; porous rock, harder at bottom, 325–403; clay, 403–413; mud, 413–420; basalt, 420–473. Well not completed in November, 1907.
6	J. Agzel.....	23	12	29	...do....	456	100	Water at 450; basalt at 370.
7	Mrs. M. P. Jordan...	22	12	29	...do....	450	400	Water at 430. Strata passed through: Soil, 0–130; quicksand, 130–170; blue clay, 170–425; basalt, 425–450.
8	Peter Kalkwauf.....	3	12	29	...do....	395	[b] 300	
9	W. B. Chamberlain.....		12	24	Dug and drilled.	140	100	Soil, 0–8; loose gravel, 8–16; cement gravel, 16–70; clay, 70–105; quicksand, 105–140. Completed June, 1910.
10	.....	17	12	23	Dug....	[b] 20	17	
11	G. Meeboer.....	24	12	22	Drilled..	204	172	Water at 187. Strata passed through: Gravel, 0–65; basalt, 65–204.
12	Abram van der Linde.	24	12	22	...do....	96	55	Water at 72.
13	John Cudhie.....	29	12	22	Drilled..	186	.....	No water; through decomposed basalt to fresh basalt.
14	J. Merriam Smith...	.....	10	30	Drilled..	[c] 327	.....	Water at about 180.
15	Northern Pacific Ry.	11	11	30	Dug.....	151	115	In gravel of Eltopia Coulee.
16	.....	4	10	31	Dug.....	[b] 50	.....	No water; through basaltic gravel to solid basalt.
17	Mr. Hillard.....	.....	10	23	Drilled..	75	.....	No water at 75; drilling in December, 1907.
18	.....	2	10	18	Dug.....	.....	16	In valley filling.
19	Grandview school district.	.....	9	24	Drilled..	62	.....	Ellensburg formation, 0–35; basalt, 35–62.
20	Town of Grandview.	23	9	24	Drilled..	132	[b] 60	Water at 60 and at 130.
21	George Houghmaster.	33	9	24	Drilled..	113	8	Water at 57; 100 feet of basalt; white sandstone at bottom.
22	Northern Pacific Ry.	30	9	27	.....	[b] 50	.....	Water at about river level.
23	Mr. McCauzland.....	.....	9	27	Drilled..	233	80	Water under artesian head.
24	B. B. Swearingen...	12	9	27	Drilled..	300	135	Drilling in June, 1908. Water at 165, 200, and 250. Tested 100 gallons a minute.
25	A. E. Burroughs....	24	9	30	Dug.....	50	48	In gravel of coulee.
26	Foster Bros.....	.....	9	30	Dug.....	110	106	In gravel of coulee.
27	Mr. Amond.....	30	8	29	Dug.....	16	14	In ravine.
28	Kelso Bros.....	16	8	27	Drilled..	800	.....	A little water; not completed in November, 1907.
29	Adolph Perrault....	33	8	26	Drilled..	132	30	Supplies neighbors; 3-horsepower engine.
30	Yakima County.....	16	8	26	Drilled..	832	300	Supplies neighbors; 12-horsepower engine; yields 5,000 gallons a day during summer

[a] Numbers correspond to numbers on the map (Pl. I).
[b] Approximate.
[c] Reported.

Wells in south-central Washington—Continued.

No.	Owner.	Location.			Class of well.	Depth.	Depth to water.	Remarks (depths in feet).
		Sec.	T. N.	R. E.				
						Feet.	*Feet.*	
31	W. H. Hayden	8	8	26	Drilled..	496	300	Supplies neighbors; 14-horsepower engine; yields 20,000 to 30,000 gallons a day during summer. A little water at 200; main supply at 496.
32	Mr. Frances	35	8	25	Drilled..	[a] 150	100	Supplies neighbors; 2-horsepower engine; yields 4,000 to 5,000 gallons a day during summer.
33	I. W. Carter	21	8	25	Drilled..	423	200	Soil, 0–12; basalt (?), 12–100; white clay, 100–200.
34			8	23	Dug		45	Through basaltic gravel.
35	Town of Mabton	1	8	22	Drilled..	1,161		Not used. Wood at 850 and 1,090. Below 850 a succession of water-bearing strata.
36	A. F. Wattenberger	28	7	21	Drilled..	202	166	Water at 196.
37	L. Spencer	27	7	21	Drilled..	96	Flows.	Water at 94½.
38	Arthur King		7	22	Drilled..	239	200	
39	Will Yeckel		7	22	Drilled..	225		Drilling in November, 1907. A little water at 187 and 206.
40	J. V. Rhydholm		7	24	Drilled..	110	[b] 100	
41	Mr. Buckingham		7	24	Drilled..	404		Windmill pumps out in 8 hours.
42	William Markham		7	25	Drilled..	504		Engine and windmill.
43	Louis Anderson	14	7	26	Drilled..	350	225	Supplies neighbors; 5-horsepower engine and windmill; yields 10,000 gallons a day during summer; a little water at 225, main flow at 335.
44	Mr. Baker		7	27	Drilled..	250		Engine.
45			7	28	Dug	20	18	Small seepage in canyon.
46	John Rose		7	29	Dug	66	60	Water at 60; soil 0–26, basalt 26–66.
47	Mr. Boofer		7	29	Dug	20	15	Seepage supply, about 1,000 gallons a day.
48	Don Creswell		7	29	Dug	35	20	Formerly Cottonwood Spring.
49	Will Richards		7	29	Dug	[b] 15	12	Seepage supply, about 500 gallons a day.
50	A. H. Richards	29	7	30	Drilled..	1,100	700	Small supply, not used; about 125 gallons an hour at 700, lost on drilling deeper.
51	S. E. Walker	2	6	28	Dug	14	12	Small seepage.
52	Joe Slaybough	24	6	23	Drilled..	124	50	Water at about 90.
53	John Doosey	14	6	21	Drilled..	146	100	
54	F. W. Sanderson		6	21	Drilled..	309	45	Small supply; water at 65 rose within 15 feet of surface.
55	J. Martinet		6	21	Drilled..	131	70	Water at 131.
56	Town of Bickleton	16	6	20	Dug		20	
57	J. G. Gateburg		5	20	Drilled..	170	124	
58	John Lund	30	5	20	Dug	20	15	In swale; water at 8 in well 50 yards west.
59	Samuel Sinclair	31	5	20	Dug	40	35	
60		3	5	23	Dug	30	30	In dry drainage channel.
61	H. P. Hansen	10	5	23	Drilled..	112		No water; not completed in October, 1907; soil, 0–20; basalt, 20–100.
62	C. M. Jensen		5	23	Drilled..	130	128	Water at 111.
63	Nels Sturgard		5	23	Dug	17	14	Seepage in canyon.
64		14	5	24	Drilled..	185	120	Soil, 0–100; basalt, 100–185.
65	W. F. Crow		4	24	Drilled..	162	Flows.	Yields about 1 second-foot; through unconsolidated material.
66	M. E. Carley	7	4	24	Drilled..	176	Flows.	Yields about ¾ second-foot; small flow at 128, main flow from 142.

[a] Reported. [b] Approximate.

Springs in south-central Washington.

No.[a]	Name.	Location.			Flow.	Date.	Remarks.
		Sec.	T. N.	R. E.			
					Miner's inches.[b]	1907.	
1	Rattlesnake	21	12	25	60–70	Nov. 29	
2	Barrel	13	12	23	½	Nov. 29	
3	Trough	15	12	22	½	Nov. 18	
4	Nicolai's	15	11	23	30–40	Nov. 29	
5	Unnamed	8	11	25	.....	.....	
6	Cliff	.....	9	25	.....	Oct. 3	Yield said to be a barrel an hour.
7	Badger	.....	8	28	.....	Oct. 4	Yields less than a barrel an hour.
8	Beckner	36	7	20	[c] 1	Oct. 12	
9	Unnamed	.....	7	22	.....	.....	Small yield; in coulee.
10	McKinley	.....	6	24	.....	Oct. 9	Yields several barrels a day.
11	Unnamed	21	5	25	.....	Oct. 8	Small seepage.
12	Cold	7	4	20	5–10	Oct. 11	

[a] Numbers correspond to numbers on the map (Pl. I).
[b] A miner's inch is equivalent to about 9 gallons a minute.
[c] Approximate.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 317

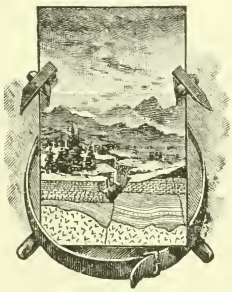
GEOLOGY AND UNDERGROUND WATERS

OF THE

WICHITA REGION, NORTH-CENTRAL TEXAS

BY

C. H. GORDON



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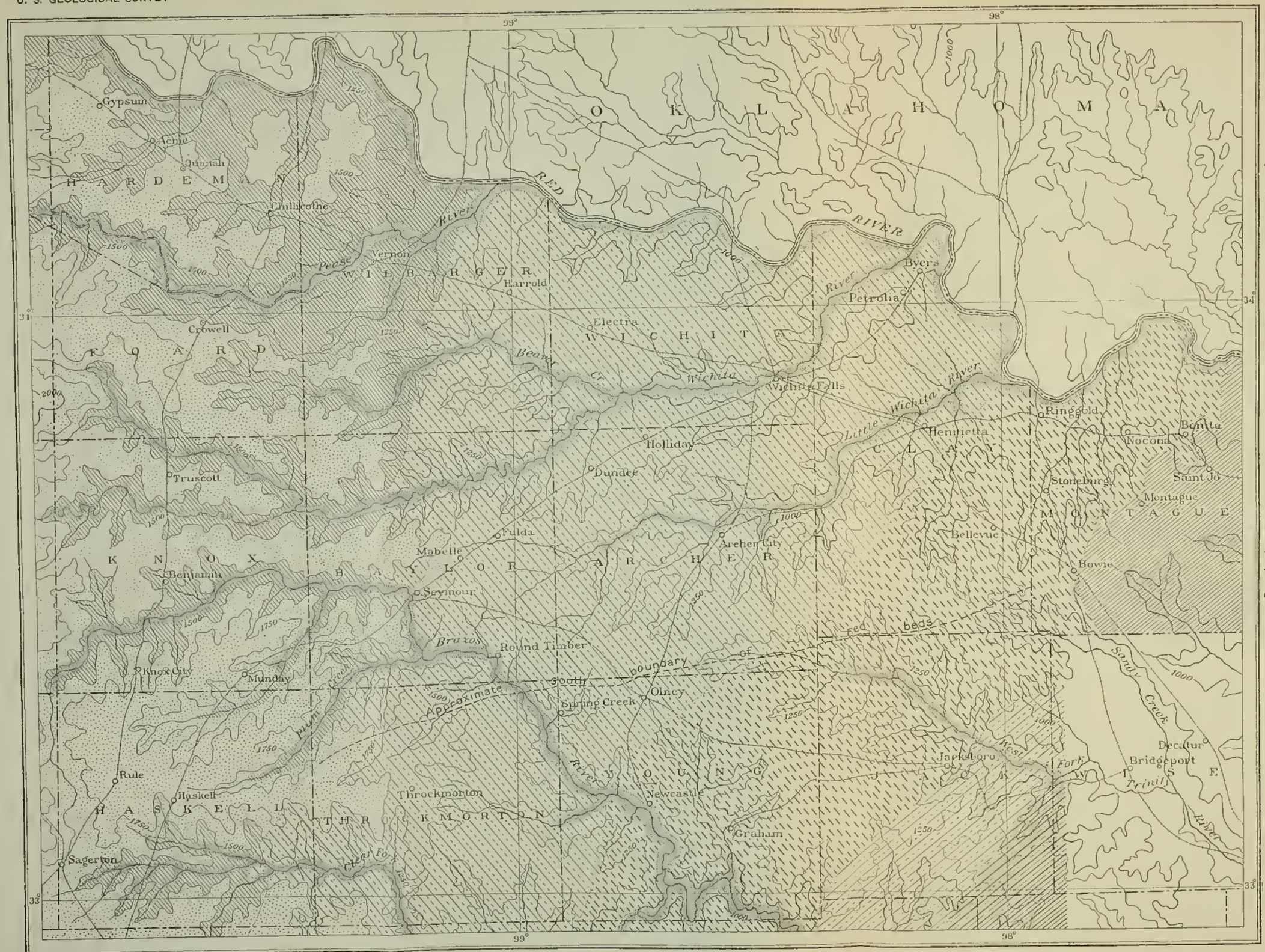

LEGEND

Recent	Alluvium	QUATERNARY
Pleistocene	Seymour formation (*Sands and gravels overlain by fine silts*)	QUATERNARY
Comanche	Goodland limestone and Trinity sand	CRETACEOUS
Permian	Clear Fork and Double Mountain formations, undifferentiated (*Red and blue clays, sandy shales, and sandstones, with gypsum and some limestone. Gypsum more abundant in the upper beds*)	CARBONIFEROUS
Permian	Wichita formation (*Red and blue clays and sandstones, with limestones in the upper part of the formation*)	CARBONIFEROUS
Permian	Cisco formation (*Clay, shale, conglomerate, and sandstone, with some limestone and coal. The coal is in the upper half of the formation. There are some limestones near the top and also near the bottom*)	CARBONIFEROUS
Pennsylvanian	Canyon formation (*Limestones with interbedded clay, shale, sandstone, and conglomerate*)	CARBONIFEROUS
Pennsylvanian	Strawn formation (*Alternating beds of sandstone and clay, with some conglomerate and shale; the lower 1000 feet consists of blue and black clay with scattered beds of limestone, sandstone, or sandy shale, and at the top a coal seam*)	CARBONIFEROUS

Base compiled from R. T. Hill's map of Texas in Topographic Folio 3, U. S. Geological Survey, and U. S. Post Route map of Texas

10 0 10 20 30 40 50 Miles

Contour interval 250 feet

1912

GEOLOGIC SKETCH MAP OF THE WICHITA REGION, NORTH-CENTRAL TEXAS.

GEOLOGY AND UNDERGROUND WATERS OF THE WICHITA REGION, NORTH-CENTRAL TEXAS.

By C. H. Gordon.

INTRODUCTION.

Location and area.—The region considered in this report is a part of north-central Texas. Red River forms its northern boundary, and it comprises Montague, Clay, Wichita, Wilbarger, Hardeman, Foard, Knox, Baylor, Archer, Jack, Young, Throckmorton, and Haskell counties. Its area is approximately 11,139 square miles, and its population, according to the census of 1910, is 158,046, an increase of 78,215 over the population in 1900.

The United States Geological Survey has prepared atlas sheets covering Montague County and the tier of counties bordering the Wichita region on the south (Palo Pinto, Stephens, Shackelford, and Jones), but for the remaining portion no accurate base maps are available. Plate I is based chiefly on Hill's map of Texas.

Purpose of the investigation.—This region depends for its water supplies almost wholly on surface waters, which are insufficient, so that the problem of finding underground sources of potable water in sufficient quantities is of great importance. The field investigations were directed to the determination of the geologic conditions with a view to locating water-bearing formations that might be available sources of water. The region is one of interest to geologists because of the stratigraphic problems occurring within its boundaries. On these problems numerous papers have been published, in which wide differences of opinion are expressed concerning the stratigraphic relations of the beds. The explanation of the discordant views concerning the stratigraphy of the region is found (1) in the diverse character of the formations and the lack of satisfactory exposures, which render the tracing of formations and their correlation even at points not far distant from each other difficult or impossible; (2) in the lack of detailed investigation and of accurate maps; and (3) in the lack of knowledge in regard to the life and relations of the American Permian.

Field work and acknowledgments.—Portions of the field seasons of each of the years 1906 and 1907 were devoted to investigations for this report. During the first season the work was done by the writer alone. During the second season he was assisted by Messrs. Leon F. Russ, of the University of Texas, and Frank Brock, of the University of Kansas, to whose efficient services he is much indebted. The necessity for rapid work in a region so difficult of study makes the adequate treatment of the stratigraphic problem impossible, but it is believed that the results of the investigation constitute an important if small contribution to the solution of the problem connected with the much-discussed "Red Beds" of Texas.

LITERATURE.

Much of the literature relating to this region is widely scattered, and no attempt is made to present here a complete bibliography of it. The effort has been made, however, to compile a list of the writings of chief importance on the problems involved in the preparation of this report. For a more exhaustive record of the publications relating to the geology of Texas the reader is referred to the excellent bibliographies of Hill [1] and Simonds.[2]

Adams, G. I., Stratigraphic relations of the Red Beds to the Carboniferous and Permian in northern Texas: Bull. Geol. Soc. America, vol. 14, 1903, pp. 191–200.

Beede, J. W., Invertebrate paleontology of the upper Permian Red Beds of Oklahoma and the panhandle of Texas: Sci. Bull. Kansas Univ., vol. 4, No. 3, March, 1907, pp. 115–172.

Case, E. C., New or little-known vertebrates from the Permian of Texas: Jour. Geology, vol. 11, 1903, pp. 394–402.

——— The osteology of *Embolophorus dolovianus*, with an attempted restoration: Jour. Geology, vol. 11, 1903, pp. 1–28.

——— The character of the Wichita and Clear Fork divisions of the Permian of Texas: Bull. Am. Mus. Nat. Hist., vol. 23, 1907, pp. 659–664.

——— The Permian of Texas: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 9–12.

——— On the value of the evidence furnished by vertebrate fossils of age of certain so-called Permian beds in America: Jour. Geology, vol. 16, 1908, pp. 572–580.

Cope, E. D., Description of extinct Batrachia and Reptilia from the Permian formation of Texas: Proc. Am. Philos. Soc., vol. 17, 1878, pp. 518 et seq.

——— Contributions to the knowledge of the fauna of the Permian formation of Texas and the Indian Territory: Proc. Am. Philos. Soc. (various papers).

Cummins, W. F., The Permian of Texas and its overlying beds: First Ann. Rept. Texas Geol. Survey, 1889, pp. 183–189.

——— Report on the geology of northern Texas: Second Ann. Rept. Texas Geol. Survey, 1890, pp. 357–552.

——— Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1892, pp. 177–238.

——— Texas Permian: Trans. Texas Acad. Sci., vol. 2, 1897, pp. 93–98.

Drake, N. F., Report on the Colorado coal field: Fourth Ann. Rept. Texas Geol. Survey, 1892, pp. 355–460.

[1] Hill, R. T., The present condition of knowledge of the geology of Texas: Bull. U. S. Geol. Survey No. 45, 1887.

[2] Simonds, F. W., A record of the geology of Texas for the decade ending Dec. 31, 1896. Trans. Texas Acad. Sci., vol. 3, 1899, pp. 17–296.

DUMBLE, E. T., Existence of artesian waters west of the ninety-seventh meridian: S. Ex. Doc. No. 222, 51st Cong., 1st sess., 1890, pp. 99–102.

——— Localities and horizons of Permian vertebrate fossils in Texas: Jour. Geology, vol. 16, 1908, pp. 737–745.

FONTAINE, W. M., Fossil plants from the Permian of Texas: Bull. Geol. Soc. America, vol. 13, 1891, p. 217.

GOULD, C. N., Geology and water resources of the western portion of the panhandle of Texas: Water-Supply Paper U. S. Geol. Survey No. 154, 1907.

GORDON, C. H., GIRTY, G. H., and WHITE, DAVID, The Wichita formation of northern Texas: Jour. Geology, vol. 19, 1911, pp. 110–134.

HILL, R. T., Classification and origin of the chief geographic features of the Texas region: Am. Geologist, vol. 5, 1890, pp. 9–29; 68–80.

HYATT, ALPHEUS, Carboniferous cephalopods: Second Ann. Rept. Texas Geol. Survey, 1890, pp. 327–356; Fourth Ann. Rept. Texas Geol. Survey, 1892, pp. 377–474.

MARCOU, JULES, On the classification of the Dyas, Trias, and Jura in northwest Texas: Am. Geologist, vol. 10, 1892, pp. 369–377.

PROSSER, C. S., The anthracolithic or upper Paleozoic rocks of Kansas and related regions: Jour. Geology, vol. 18, 1910, pp. 125–161.

ROESLER, F. E., Location of wells within the area of the ninety-seventh meridian and east of the foothills of the Rocky Mountains: S. Ex. Doc. No. 222, 51st Cong., 1st sess., 1890, pp. 243–319.

SCHMITZ, E. J., Copper ores in the Permian of Texas: Trans. Am. Inst. Min. Eng., vol. 26, 1896, pp. 97–108.

TARR, R. S., Superimposition of drainage in central Texas: Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 359–362.

——— Preliminary report on the coal fields of the Colorado River: First Ann. Rept. Texas Geol. Survey, 1889, pp. 199–216.

THOMPSON, R. A., Soils, water supply, and irrigation of the Colorado coal field: Fourth Ann. Rept. Texas Geol. Survey, 1892, pp. 477–481.

WEITZEL, R. S., The coal field of Texas (extract of a paper read before the Ohio Institute of Mining Engineers): Eng. and Min. Jour., vol. 50, 1890, pp. 214–216.

WHITE, C. A., On the fauna of the Permian of Baylor, Archer, and Wichita counties, Tex.: Am. Naturalist, vol. 22, 1888, p. 926.

——— On the Permian formation of Texas: Am. Naturalist, vol. 23, 1889, pp. 109–128.

——— Administrative report, Mesozoic division of invertebrate paleontology: Tenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1890, pp. 162–165.

——— The Texas Permian and its Mesozoic types of fossils: Bull. U. S. Geol. Survey No. 77, 1891, p. 51; Trans. Am. Philos. Soc., vol. 16, pp. 285–288.

WHITE, I. C., Fossil plants of the Wichita or Permian beds of Texas: Bull. Geol. Soc. America, vol. 3, 1892, pp. 217–218.

WILLISTON, S. W., New or little-known Permian vertebrates: Jour. Geology, vol. 17, 1909, pp. 636–658.

——— Dissorophus Cope: Jour. Geology, vol. 18, 1910, pp. 526–536.

——— New Permian reptiles: Rhachitomous vertebræ: Jour. Geology, vol. 18, 1910, pp. 585–600.

——— Restoration of *Seymouria baylorensis* Broili: Jour. Geology, vol. 19, 1911, pp. 232–237.

PHYSIOGRAPHY.

The surface of the region constitutes in the main a gently eastward-sloping plain dissected by well-marked systems of drainage. It has an elevation of about 1,000 feet above sea level at the east and about 1,600 feet at the west, showing an average eastward slope of about 5.5 feet to the mile. The valleys are relatively wide and are bounded

by abrupt escarpments within which the rivers flow in broad, shallow channels. During stages of high water the channels may be filled from side to side, but in dry seasons the streams may shrink to the dimensions of brooks and may wind about through the sands of the wide flood plain.

Extending through Shackelford, Throckmorton, and Baylor counties, from Albany north to the vicinity of Harrold, is a series of rock terraces along which the surface descends in a succession of escarpments 150 to 250 feet in height. These scarps mark the outcropping edges of limestone strata which constitute a prominent feature of the Wichita formation toward the south. Scattered over the plain surface in the western part of the area are many eminences rising from 100 to 200 feet above the general level; they are remnants of an older plain surface, the main portion of which lies to the west of the area.

Owing to the change in the character of the formations in the terrace belt in their northward extensions, the contrast in relief that is notable in the western and eastern portions of the region becomes less well defined in the northern portion and appears only in the increase of gradient in the surface level, as shown, for example, in the profile of the Fort Worth & Denver City Railway.

The plain lying to the east of the terrace belt is moderately dissected by the streams and their tributaries, but the relief on the whole is not so marked as in the higher surfaces on the west; in general the stream valleys are wider and shallower and the interstream areas more worn and rounded. Instead, therefore, of level interstream areas trenched by narrow and deep channels, as in the western part of the region, the eastern part has an irregular rolling surface of moderate relief. The explanation of these physiographic features is to be found in the effects of erosion as determined in large part apparently by the character of the rocks.

CLIMATE.

The region lies at the border of the semiarid portion of the United States. The mean annual rainfall ranges between 32 inches in the eastern and 23 inches in the western part of the region. The mean annual temperature is 64° F. in the eastern part and 60° F. in the western part.

The line of 20 inches of annual rainfall, which is the approximate limit of agriculture without irrigation, follows closely the foot of the Llano Estacado, about 60 miles west of the region here discussed. The average annual rainfall in the Wichita region is 29 inches. In the eastern half of the region the average is nearly 31 inches; in the western half it is about 26.5 inches. The westernmost tier of counties, Hardeman, Foard, Knox, and Haskell, have an average

of 25 inches. The maximum precipitation occurs in the easternmost counties, Montague having 35 inches, Clay 32 inches, and Jack 33 inches. The records show in general a regular decrease in rainfall from the east toward the west, but Wichita County departs from the rule in having an average fall of only 25 inches, which is less than that of any of its adjoining counties—Wilbarger and Baylor on the west having 28 inches each, Archer on the south 30 inches, and Clay on the east 32 inches. The rainfall in this portion of the State comes mainly from the Gulf of Mexico and descends most abundantly in the winter.

SURFACE WATERS.

The drainage of the region is toward the east and southeast, in the direction of the general slope. The northern half is drained by tributaries of Red River, chief of which are Wichita, Little Wichita, and Pease rivers. The southwestern portion is drained by the Brazos through its two main tributaries—Salt and Clear forks—and the southeastern portion is drained by the West Fork of Trinity River. Only the large streams have permanent supplies of water, and in dry weather even these dwindle to mere brooks.

The unindurated character of the formations over considerable portions of the district favors rapid erosion during times of freshet and the larger streams are choked by the abundance of material supplied to them by their tributaries. They partake, therefore, of the nature of overloaded streams. Except in times of freshet the bottoms of the wide channels are covered with sand bars, and much of the water sinks below the surface. Owing to the treacherous character of these beds of sand, the fording of the streams often becomes a matter of considerable difficulty and even of danger.

Interesting examples of the physiographic development of valleys are presented in the streams of the region, especially by the Brazos and its tributaries, Salt and Clear forks. Tarr [1] has called attention to the superimposed character of the drainage of the region and to the differences in the work accomplished by the Brazos and the Colorado. He remarks that the Brazos, owing to the accidental selection of a region of softer rocks, has had the advantage in the struggle for drainage territory and has been enabled "to push the divide close up to the Colorado in territory which under more favorable circumstances should belong to the latter stream." The general course of the Brazos and its tributaries has been selected without reference to the structural character of the beds upon which it flows; nevertheless, the effect of variations in the hardness of the rocks is clearly registered in the differences in the work accomplished by the streams in the different parts of their courses. Both the Clear Fork, from the point

[1] Tarr, R. S., Superimposition of the drainage in central Texas: Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 359–362.

where it enters Shackelford County to its junction with the main stream, and the Brazos itself, to and beyond the point where it leaves the region, flow with serpentine courses in comparatively narrow valleys with more or less prominent rock escarpments. In this portion of its course the Brazos has been working upon a series of rocks in which hard limestones are conspicuous. On the other hand, the Salt Fork flows throughout most of its course upon softer beds in which it has excavated a valley much wider than that of the Clear Fork or that of the main stream below the junction. The serpentine course so characteristic of the Clear Fork and of portions of the Brazos is not a feature of the Salt Fork. West of Seymour the stream flows in a valley 2 to 4 miles in width which has been excavated to a depth of 50 to 60 feet below the general plain level. An important stage in its physiographic history is recorded in the remnants of a terrace which occurs about 25 feet above the present flood plain. At Seymour the river crosses a belt of limestone and for several miles is confined within a rock-walled valley not exceeding a mile in width. After passing this obstruction the valley again widens to 4 or 5 miles. The 25-foot terrace probably finds its explanation in the obstruction at Seymour, but their relation has yet to be determined.

DEEP WATERS.

Occurrence.—The water which permeates the rocks has its source in the rainfall. It does not come wholly nor, it may be, mainly from the local precipitation, but may be derived from some far-distant region where the rocks come to the surface and form catchment areas for the rain. This is especially the case where deep-lying rocks are overlain by impervious strata which effectually prevent the water falling locally from finding its way into the strata below. Shallow wells derive their supplies from the rainfall of the immediate locality or from closely adjacent regions.

The upper surface of the ground water, called the water table, conforms in a general way to the surface of the ground, being higher under elevated areas than under valleys. The depth to the water level is, however, generally greater under the hills than under the valleys. Where the streams have cut their valleys to the level of the water table, springs and seeps abound along the valley sides. The fact that the water obtained from shallow wells comes from the surface suggests the dangers involved in their use, especially where they are most liable to contamination, as in towns and cities. Many people suppose that any contaminating elements absorbed at the surface by the water will be soon removed in its course through the ground, but this is not invariably the case. Some deleterious substances go into solution and can not then be removed by filtration, and certain injurious microbes sometimes present along with harmless

ones in the soil waters may find their way for long distances underground. The waters obtained from deeper sources are rarely subject to surface contamination.

Relation to rock structure.—The distribution of underground waters depends on the character and the arrangement or geologic structure of the rocks. A knowledge of the geology of the region is therefore necessary in order to understand the underground water conditions. Rocks which have had their origin as sediments at the bottom of some body of water are arranged in a succession of layers, varying according to the character and abundance of the materials supplied and the conditions under which they were deposited. Normally the different strata would lie in regular succession, the oldest being at the bottom and the youngest at the top. The strata were not laid down in a perfectly horizontal position and, moreover, in most places they have been somewhat tilted since they were deposited. In view of this inclination of the beds and of the fact that erosion has modified the surface of the land, each stratum is likely to make its appearance at the surface somewhere, under conditions determined by the character and thickness of the rock bed, the dip of the strata, and the surface relief. A rock sheet, therefore, consists of two related parts, the outcrop, or exposed portion, and the embed, or portion which is concealed. As a rule the embed is by far the larger part of the stratum. In a water-bearing stratum the outcrop is its main catchment area and the embed constitutes the storage reservoir.

The capacity of rocks for absorbing water varies greatly. Rocks of open texture, like sands, sandstones, and gravels, imbibe water freely. Rocks of close texture may be nearly or quite impervious. Thus slate, marble, and granite imbibe very little water unless they are fractured. Limestones may become water bearing through the development of spaces and channels by solution. The conditions which determine the availability of deep-lying water are (1) the presence of a water-bearing stratum capped by an impervious stratum whereby the water is prevented from being dissipated into the adjoining beds; (2) a sufficient outcrop or catchment area in a region of sufficient rainfall to furnish a water supply; (3) an inclination of the water-bearing bed not so great as to carry it too quickly beyond the reach of the drill; (4) the absence of openings which will permit the escape of the water at a level below the well; (5) such relation between the elevation of the outcrop and that of the top of the well that hydrostatic pressure will bring the water to the surface or so near to it as to be economically available by pumping.

Quality of underground waters.—All underground waters are mineralized to a greater or less extent. The composition of the waters is determined by the character of the rocks through which they pass and the kind and proportion of mineral ingredients which they take

into solution. Moreover the quantity of mineral matter taken into solution is likely to be greater in proportion to the distance from the point of entry. Hence water from shallow wells in the catchment area of formations which contain much soluble mineral matter may be fairly good, while that from the same formations under cover may be too highly charged with deleterious mineral matter to be used.

To yield abundant and satisfactory supplies of water the water-bearing stratum should be sufficiently porous to permit the free movement of the water and should contain only a small proportion of readily soluble mineral compounds which render the water bad for use. The most abundant of such substances in this area are the carbonates and sulphates of calcium, magnesium, and sodium and the chloride of sodium, or common salt. The prevailing type of water from the Permian beds is highly charged with sulphates, carbonates, calcium, magnesium, and sodium, and the water of the Carboniferous rocks is for the most part strongly impregnated with salt. The mineral ingredients of rocks are not uniformly distributed, and hence wells at different places in the same formation may yield water very unlike in quality. For example, at Graham and Jacksboro wells in close proximity to each other yield water that is wholly unlike in quality. (See analyses Nos. 2 and 3, p. 77.)

Fluctuating wells.—According to G. A. Stafford, of Belcherville, who has put down a number of wells in Montague County, water in many wells in the county whose depth is from 60 to 120 feet is lowered when the wind blows from the north. On the other hand, it is said that the water in some shallow wells is lower when the wind is from the south. The probable explanation is that the ground-water level is affected by changes in barometric pressure. With decrease in barometric pressure the water will rise, and with increase in pressure it will descend. Such wells are often called "weather wells," from the fact that they indicate the change in weather which is also indicated by the change in barometric pressure. With this phenomenon is sometimes associated a clouding or boiling of the water. This also is probably due to change in barometric pressure, which affects the water surface over a large area and causes a movement whereby the water gathers up the fine clayey material in the sandrock and thus becomes cloudy. In some wells there is a daily fluctuation, the rising and falling accompanying the daily change in pressure, or it may be the changes of temperature. The fine material in the water of this region contains a considerable percentage of iron oxide, and cloudy water taken from a well requires a considerable time to settle. This appearance is sometimes taken as an indication of oil, and some persons even assert that the water smells of oil. Although it is not improbable that oil exists in small quantities in

the rocks of this region, it is the opinion of the writer that the supposed indications of oil are due to the presence of the iron, a very small quantity of which is sufficient to give the appearance described. In favor of this conclusion is the statement of Mr. Stafford that the water, after standing for some time, tends to clear at the top by settling, whereas if oil were present it would remain at the top.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CAPACITY.

GENERAL RELATIONS.

All the rocks of this region are of sedimentary origin, except possibly a deposit at Red Bluff, near Vernon, which is said to be volcanic ash.[1] Except in the Cretaceous area in the eastern part of Montague County the basement rocks are all of Carboniferous age (Pennsylvanian or Permian). They consist of limestones, clays, shales, sandstones, and conglomerates. The shales and sandstones in many places are soft and yield readily to erosive agencies. The limestones are harder and more resistant and appear in outcropping ledges and rock terraces, which in some localities constitute notable features of the topography.

The Carboniferous strata have a general west-northwest dip of about 25 to 30 feet to the mile, though locally they are horizontal or dip in the opposite direction. No faulting or extensive folding was observed within the region. That the formations have suffered pronounced erosion is shown by the present configuration of the surface and by the indications that in former times the region was covered to a considerable depth by rocks of which only traces remain. Triassic and Jurassic beds are not known in this region, though formations of Triassic age doubtless supplied much of the material composing the Pleistocene gravel beds in the Seymour formation. Hill[2] and Tarr[3] have shown the former extension of Cretaceous rocks over large areas in central Texas from which they have been removed, though Comstock[4] takes an opposite view with reference to the "central mineral region." The only Cretaceous rocks in place within the region here considered are in the eastern part of Montague County, which belongs to the main Cretaceous area lying farther east. In the region south and west of this area remnants of Cretaceous formations occur as isolated knobs and buttes, which indicate the former extension of the Cretaceous over the Carboniferous area as far north as Wichita River and possibly into Oklahoma. Cum-

[1] Soil survey of the Vernon area: Field Operations Bur. Soils for 1902, U. S. Dept. Agr., p. 369.

[2] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 108.

[3] Tarr, R. S., Am. Geologist, vol. 9, 1892, pp. 169–178.

[4] Comstock, T. B., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 663–664.

mins [1] is of the opinion that the Cretaceous extended in a narrow belt across the southern border of the Carboniferous, but not as far north as Wichita River. The presence of worn Cretaceous fossils in abundance in the surficial gravels and sands in Haskell and Knox counties indicates the former extension of Cretaceous beds far beyond their present limits. The Tertiary appears to be unrepresented in this region, but the character of part of the material composing the Seymour formation (Pleistocene) suggests that some of it was derived from Tertiary beds whose remnants outcrop in the escarpment of the Llano Estacado to the west of this region. In the valley of the Wichita, in Wichita County, there are some gravels which may possibly be of Tertiary age. Prior to the Cretaceous period the Carboniferous strata suffered great erosion, and upon the beveled edges thus produced the Cretaceous sediments were laid down. As the Cretaceous beds dip toward the southeast, the rainfall in the Cretaceous area of this region is drained away in the same direction through the porous beds. The principal catchment area for the Carboniferous terranes probably lies west of the boundary of the Cretaceous formations.

As the surface of the land rises to the west, in the direction of the dip, the prospects of obtaining flowing wells are poor except in localities near the outcrop of the water-bearing beds where erosion has locally lowered the surface level below that of the artesian heads. Such localities exist in the southeastern part of Stephens County, the western part of Jack County, and the western part of Montague County.

CARBONIFEROUS SYSTEM.

PENNSYLVANIAN SERIES.

CLASSIFICATION.

The undoubted Pennsylvanian rocks of the region are divided into three formations, the division being based on differences in lithologic and stratigraphic character. From above downward these formations are as follows:

Section of Pennsylvanian formations in Wichita region, Texas.

	Feet.
Cisco formation (clay, shale, conglomerate, and sandstone with some limestone and coal)	800
Canyon formation (alternating beds of limestone and clay with some sandstone and conglomerate)	800
Strawn formation (alternating beds of sandstone and clay with some conglomerate and shale; the lower thousand feet consists of blue and black clay locally containing beds of limestone, sandstone, or sandy shale, and a coal seam at top)	1,900

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 370–371.

STRAWN FORMATION.

GEOLOGY.

The upper three-fourths of the Strawn formation as here defined consists of sandstones alternating with beds of blue clay. It contain some conglomerates and shales, but they are not abundant, and limestones are rare. The sandstones are usually massive, of a light gray color, which changes very little on exposure, and they afford a very good building stone. The rock consists largely of angular grains of white quartz with some red grains and some mica. It contains a little cement, which is mostly siliceous, though calcareous and argillaceous materials occur in some of the beds. The thickness of these upper beds is estimated to be 800 to 900 feet in this region. They thicken toward the south, in central Texas, where they are said to have a thickness of 3,000 feet. The lower portion, about 1,000 feet thick, was originally called by Cummins[1] the Millsap division, but these beds were later included by him in the Strawn formation, from which, he states, they are inseparable to the south. It is his later definitions of the Strawn formation that are here recognized, and "Millsap" is abandoned.[2] These lower beds have a comparatively small outcrop, being largely concealed by an overlap of the Cretaceous to the east. This overlap makes a very definite determination of their thickness impossible, but it is estimated at about 1,000 feet. The beds appear at the surface only in the extreme southeastern part of the region, the westerly dip carrying them below the surface in the remaining portion. These lower beds consist largely of blue and black clay, with a few beds of shale, sandstone, and limestone. The limestones are compact and hard and according to Cummins have been used for macadam on the streets of Dallas. Toward the south these beds, if present, are completely concealed from view by the Cretaceous. They reappear in the northern part of Erath County. According to Cummins[3] a deep well at Thurber passed through 1,000 feet of blue clay, with some sandstones and limestones, belonging to this division. At the top of the beds is the coal seam which Cummins designates No. 1.

WATER RESOURCES.

Portions of the lower beds of the Strawn formation are porous and water bearing and are reported to contain gas in some localities. At Gordon and Thurber gas and water are found in this part of the

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 372-373.

[2] Prof. Cummins, being asked for his opinion regarding the usefulness of the term "Millsap," writes as follows, under date of November 18, 1912: "It was my intention to abandon the name 'Millsap' and include the strata in the Strawn division. In all my publications after the first and second reports the name Millsap was not used. I thought it the better plan. The beds referred to the Millsap in the northern field could not be separated from the Strawn in the southern field. The name Millsap for the Texas field ought to be abandoned."

[3] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, p. 374.

formation. The water contains too much salt to be of general use, and hence these beds can not be utilized as a source of water supply. The sandstones in the upper part of the formation likewise contain an abundance of water, and in the area of its outcrop water is obtained in shallow wells at depths ranging from 15 to 50 feet. Several flowing wells in Palo Pinto County derive their supply from this formation. In one of these, at Gordon, in the southern part of the county,[1] the water-bearing stratum was found at a depth of 485 feet. The well is reported to have a flow of 1 gallon a minute of salt water accompanied by some gas. Another well, 4 miles north of Gordon, is 498 feet deep and has approximately the same flow of water.

It is not probable that in their extension under cover westward these beds would undergo any change in character that would improve the quality of the water, and hence there is little likelihood that wells sunk to this horizon would furnish potable supplies.

CANYON FORMATION.

GEOLOGY.

The Canyon formation consists of alternating beds of blue limestones and blue clays, with some sandstones and conglomerates. The limestones for the most part are massively bedded and constitute the distinguishing feature of the formation. Many of the beds are rough and irregular in texture and unsuited for building purposes, but some ledges furnish a stone of good quality. The few sandstones are more or less friable and porous. The formation has a thickness of about 800 feet. It outcrops in a narrow belt extending northeastward across Jack County. The west boundary of the formation enters at the southwest corner of the county, passes northeastward through Jacksboro and beyond, and thence curves eastward and meets the west boundary of the overlapping Cretaceous in the northern part of Wise County.

A general section of the upper part of the Canyon formation follows:

Section of upper part of Canyon formation.

	Feet.
1. Sandstones and clays (Cisco formation).	
2. Limestone	20–25
3. Sands, sandstones, and conglomerates	100±
4. Limestone, massive, with thin beds of sand	20
5. Shales	80–125
6. Sandstones with water and in places oil	10–20
7. Shales	15–20
8. Limestone	35

[1] S. Ex. Doc. No. 222, 51st Cong., 1st sess., 1890, p. 257.

WATER RESOURCES.

Limestone rocks as a rule are too dense to permit the free movement of water, but some limestones are sufficiently porous to absorb it in considerable quantities. Limestones are usually intersected by fractures, however, which offer passageways, and these the water by its solvent action enlarges, the rate at which enlargement takes place being determined by the amount of water, its character—especially as to the carbon dioxide contained in it—and the solubility of the rock. Underground channels and caverns are thus a characteristic feature of limestone regions. Near the top of the Canyon formation is a series of massively bedded limestones whose outcrop extends across the eastern part of Stephens County and the western part of Palo Pinto County, continues northeastward past Finis and Jacksboro, and disappears beneath overlying formations near the boundary between Jack and Wise counties.

In the area where the Canyon formation crops out springs are numerous and water can generally be found in shallow wells. The water is found chiefly in the sandstone beds. The second of these from the top (No. 3 in the section) appears at the surface on Little Caddo Creek and at Finis and Jacksboro. Most of the wells, however, derive their supplies from the sands (No. 6) below the second limestone. This is the horizon of the water-bearing stratum in the wells at Jacksboro. The character of the water differs greatly in wells in close proximity. In many of the wells good water is found, but not far away from a well of good water may be one in which the water is wholly unfit for use. To the west the Canyon formation is overlain by the Cisco formation. The depth of the beds increases in that direction because of the dip of the strata and the rise in the land surface. At Breckenridge, in Stephens County, the water-bearing beds of the Canyon formation can be reached at about 250 to 300 feet, and at the west boundary of Stephens County at about 1,000 feet. In neither place are flowing wells likely to be obtained, though at Breckenridge the water would doubtless rise within 50 or 100 feet of the surface.

With increasing distance from the outcrop the water tends to become more highly mineralized, and it is doubtful if good water can be obtained from these beds at distances greater than 10 or 15 miles from the outcrop.

CISCO FORMATION.

GEOLOGY.

With the close of Canyon time the clear waters of that epoch gave place to shoal water and swamps, with a corresponding change in the character of the sedimentation—limestones becoming less conspicuous;

conglomerates, sandstones, and sandy clays increasing in importance; and coal being formed here and there. These beds constitute the Cisco formation. The limestones are usually hard and irregular in texture and occur in thin isolated beds, chiefly in the lower and upper parts of the formation. About 200 to 250 feet above the base is a bed of coal called the Chaffin bed, which outcrops in the Colorado Valley, to the south, but is not found in the region here described. Near the top of the formation thin seams of coal and an abundance of plant impressions occur in bluish and gray sandy clays and sandstones, along with a few thin beds of limestone. The main seam of coal, however, designated No. 7 in the Texas reports, is somewhat above the middle of the formation. This coal is usually from 30 to 40 inches thick, with several partings of clay or shale. The outcrops of this bed of coal appear in a belt which enters Young County 8 or 9 miles east of the southwest corner, extends northward past old Fort Belknap, bears eastward to the northeast corner of the county, thence extends eastward across the north end of Jack County, and makes its last appearance in the vicinity of Bowie, Montague County. Near Belknap it is underlain by 25 to 30 feet of shaly sandstone, beneath which is a bed of limestone underlain by another seam of coal 12 to 15 inches in thickness. This seam appears to be local, as it has not been found elsewhere.

A feature of importance in the Cisco formation and one which it shares with the next succeeding formation is the series of changes observed as the formation is traced northward along the strike. These changes relate both to variation in lithologic character and to thickness of beds. In the Colorado Valley, interstratified with the sandstones, clays, and conglomerates, are six or more beds of limestone, each from 5 to 25 feet thick and all aggregating a thickness of 100 to 150 feet. In the southern part of the Brazos Valley the calcareous divisions are only about half as thick as they are farther south, and the clays show a corresponding increase in thickness. In Young County the calcareous material diminishes northward at an increased rate until at the northern boundary of the county the limestones have practically disappeared, and beyond that point they are represented apparently by irregular nodular masses of earthy limestone in a matrix of clay. With the thinning out of the limestones the shales and sandstones increase in thickness. In Stephens County and farther south the shales are prevailingly blue and the sandstones gray. Red beds are dispersed sparingly through the formation. The blues gradually give place to reds until in the vicinity of Red River the red color dominates. In this part of the region the rocks consist, for the most part, of red sandstones, clays, and sandy shales, with a few beds of blue shale and bluish to grayish white sandstones. Limestones are conspicuously absent.

The thickness of the Cisco formation in the southern part of the region is estimated to be 700 to 800 feet. As to its thickness in the "Red Beds" area no very definite statement can be made. The transitional character of the sediments offers a serious obstacle to the determination of dip. In the main the formations appear to dip slightly west-northwest. Locally the dip may reach 40 feet or more to the mile, but for the formation in general it is believed that 25 to 30 feet to the mile is a fair approximation for both these beds and the overlying beds of the "Red Beds" area. Toward the south the strata have a slightly steeper dip.[1]

The area underlain by the Cisco is about 25 miles wide at the southern boundary of Young County, but widens somewhat to the northeast. In the southern area the boundaries are clearly defined by the prominent ledges of limestone that mark the top of the Canyon formation on the east and those at the base of the Wichita formation on the west. Owing to the changes that take place in the formation toward the north, the boundaries are not so clearly determinable in that part of the region. In northern Wise County and in Montague County the Cisco is in part covered by overlap of the Cretaceous. As the conditions of sedimentation were apparently much the same at the close of the Cisco epoch and the beginning of the Wichita epoch, no clear line of division can be made out between these formations in this area. It is to be understood, therefore, that north of Young County the boundary as indicated on the map is an approximation only. In Stephens and Young counties the Cisco is in general highly fossiliferous.

At Graham Salt Creek flows at the base of an escarpment which gave the following section:

Section on west bank of Salt Creek, Graham, Tex.

	Feet.
1. Coarse conglomerate of siliceous pebbles in a matrix of sand; locally the rock varies to a white or ferruginous sandstone; forms top of prominent ridge	10
2. Blue shale, highly fossiliferous	50
3. Layer of hard blue fossiliferous limestone	1½
4. Dark-blue shale, darker and carbonaceous below; a layer of sandy shale 3 feet thick 10 feet above the base	50
5. Blue arenaceous shales and soft shaly sandstones	15
6. Bluish-white sandstone, irregularly indurated; bedding irregular and surface uneven; more or less conglomeratic and containing numerous impressions of plants, also iron concretions of brown iron ore; in places this bed resembles the upper conglomerate (1); exposed	5

[1] In a study of the oil and gas fields of Wichita and Clay counties, made for the Texas Bureau of Economic Geology since this report was written, J. A. Udden (Bull. Univ. Texas No. 246, 1912, pp. 61, 62) records a series of detailed observations on the attitude of the strata, from which he concludes that the strata lie essentially horizontal in an east-west line but are affected by minor flexures constituting shallow and wide anticlines and synclines trending east-southeast to west-northwest.

The shale underlying the upper bed of conglomerate is filled with excellently preserved fossils which strew the surface of the weathered slopes. The following is a list of the forms collected, a number of which are new. They were identified by George H. Girty:

Cyathaxonia n. sp.
Cyathaxonia n. sp. var.
Lithostrotion ? sp.
Syringopora ? sp.
Polypora 2 sp.
Fenestella sp.
Synocladia biserialis.
Fistulipora sp.
Rhombopora lepidodendroides.
Crania sp.
Lingulidiscina sp.
Derbya sp.
Chonetes n. sp. aff. geinitzianus.
Productus semireticulatus.
Productus nebraskensis.
Marginifera lasallensis.
Marginifera wabashensis.
Spirifer cameratus.
Ambocœlia planoconvexa.
Hustedia mormoni.
Pugnax osagensis.
Pugnax n. sp.
Nucula ventricosa.
Leda bellistriata.
Conocardium sp.
Deltopecten sp.
Solenomya sp.
Edmondia gibbosa.
Astartella vera.
Patellostium montfortianum.
Bellerophon percarinatus.
Euphemus nodicarinatus.
Trepospira sphærulata.
Pleurotomaria conoformis?
Pleurotomaria subconstricta?
Pleurotomaria 2 sp.
Meekospira sp.
Meekospira ? sp.
Sphærodoma sp.
Euomphalus catilloides.
Orthoceras rushense.
Chonetes sp.
Crinoidal fragments.

Cummins [1] made a section in the same locality, which is practically identical with the section given above, though arranged in reverse order. The following is a list of the fossils reported by him [2] from bed No. 2:

Allorisma subcuneata.
Bellerophon percarinatus.
Bellerophon carbonarius.
Euomphalus rugosus.
Lophophyllum proliferum.
Pinna peracuta.
Pleurotomaria sphærulata.
Pleurotomaria tabulata.
Productus cora.
Productus costatus.
Productus longispinus.
Productus nebrascensis.
Schizodus wheeleri.
Spirifer cameratus.
Spirifer lineatus.
Spiriferina kentuckyensis.
Zaphrentis spinulifera.
Hemipronites crassus.
Nucula ventricosa.
Rhynchonella uta?
Myalina subquadrata.
Chætetes milleporaceus.
Orthoceras rushensis.
Conocardium obliquum.
Aviculopecten occidentalis.

Beds of red clay make their appearance south of Young County, but they increase notably to the north, especially in the upper part of the formation along with the diminution of the limestones, and they constitute the dominant feature of the formation in eastern Clay and western Montague counties.

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, p. 378. [2] Idem, p. 362.

WATER RESOURCES.

Most of the sandstones of the Cisco formation are water bearing in varying degree, but there appear to be few persistent water-bearing strata. An exception is a sand in the lower part of the formation, which is the source of supply for a large number of wells in eastern Stephens and Young counties and western Jack County. The flowing wells at Wayland, in Stephens County, and those west and northwest of Jacksboro probably draw their supplies from this sand. In some wells of this area water is found in a limestone associated with the sand.

The water from surface wells in the lower beds of the Cisco is in general good, though in some wells it is strongly mineralized. The water from the higher beds is usually too strongly mineralized for general use, but there are some exceptions to the rule. The contrast in the character of the water from wells in this part of the formation is shown by the analyses of water of wells at Graham, given on page 77. On the west the Cisco formation is overlain by the Wichita formation, and the basal water-bearing beds can be reached only at considerable depths. In the vicinity of Albany, in Shackelford County, the depth to these beds is estimated to be 1,300 to 1,400 feet. Moreover, with increasing distance under cover, the water of these beds is probably too highly mineralized for use.

PERMIAN SERIES.

CLASSIFICATION.

Although much has been written concerning the beds between the Cisco formation and the Triassic beds which underlie the "Staked Plains," much detailed stratigraphic work remains to be done in this region before authoritative statements can be made about the classification of these beds. On the evidence of fossil remains found chiefly in the lower beds in Baylor and Archer counties, these strata are now assigned by most geologists to the Permian. These rocks as they exist in the Wichita region were subdivided by Cummins[1] into the Wichita, Clear Fork, and Double Mountain formations. The lowest formation, the Wichita, consisting mainly of red clays and sandstones, is seemingly a near-shore or delta deposit, and in it are found the remains of reptiles and plants of Permian age. Interstratified with the clays and sandstones in the upper part of the formation are beds of limestone containing marine invertebrates, of which a large proportion are Pennsylvanian types and few, if any, are considered characteristic of the Permian of Europe. South of Baylor County the Clear Fork formation rests conformably upon marine strata, consisting mainly of blue clays and shales, including considerable thicknesses

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 400–424.

of limestone containing marine invertebrates. Neither reptilian nor plant remains have been reported from these beds. The Pennsylvanian aspect of the fauna led to the assignment of these beds, under the name "Albany," to the Pennsylvanian in the earlier reports, although they were recognized by some as being possibly of Permian age.[1]

Subsequently Cummins [2] asserted the equivalency of the Wichita and the "Albany" formations and recommended the abandonment of the name "Albany." Adams [3] corroborated Cummins's conclusion as to the equivalency of the beds included in the Wichita and "Albany" formations, but recommended the abandonment of all the names, Wichita, Clear Fork, and Double Mountain, as "having no stratigraphic significance." In a paper by the writer and others [4] Cummins's conclusion as to the identity of the "Albany" with the Wichita and likewise the Permian age of the formation is confirmed. It is shown also that the definition of the Wichita as a formation is sufficiently established to warrant the retention of the name, and that usage is followed in this report. It is to be noted, however, that some limestones in Baylor County which Cummins regarded as belonging to the Clear Fork are the equivalents of the upper beds of the "Albany" and are here included in the Wichita. The upper Permian beds included under the names Clear Fork and Double Mountain in the Texas reports have had very little study and no attempt has been made to determine a definite line of division between the two formations. In this report these beds are classed as undifferentiated Clear Fork and Double Mountain.

WICHITA FORMATION.

GEOLOGY.

Character.—The Wichita formation underlies practically the whole of Wichita, Baylor, Throckmorton, and Shackelford counties, a considerable part of Clay and Archer counties, and a small part of Young County. In Shackelford County it consists of blue clays and shales with thick beds of limestones which, on account of their greater resistance to erosion, crop out in a series of eastward-facing rock scarps. The limestones, which constitute about a third of the formation, are blue, gray, and yellowish and for the most part massively bedded. They are generally hard, semicrystalline to compact, but some beds are friable and chalky and others are rough and earthy in texture. Thick beds and thin and shaly beds alternate. The

[1] Drake, N. F., Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 371. Tarr, R. S., Bull. Texas Geol. Survey No. 3, 1892, pp. 14–18.

[2] Cummins, W. F., Trans. Texas Acad. Sci., vol. 2, 1897, pp. 93–98.

[3] Adams, G. I., Bull. Geol. Soc. America, vol. 14, 1903, p. 198.

[4] Gordon, C. H., Girty, G. H., and White, David, The Wichita formation of northern Texas: Jour. Geology, vol. 19, 1911, pp. 110–134.

remainder of the formation consists of blue, gray, and black shales. The limestones contain an abundance of marine fossils, but well-preserved specimens are difficult to obtain.

Farther north there is a marked diminution in the proportion of calcareous sediments with a cor esponding increase in argillaceous and arenaceous materials. Some of the clay beds in Shackelford County are sandy, but toward the north the sandy sediments become more and more prominent, many of the layers taking on a red color. Red, white, and yellowish sandstone beds also make their appearance and constitute a marked feature of the formation in Archer and eastern Baylor counties. The red sediments increase in amount northward until in northern Throckmorton County and beyond the red color dominates in the formation.

Throughout the northern area the clays are red or red mottled with bluish-white and drab colors. The red clays contain an abundance of nodular concretions of irregular shape, ranging from those the size of a pea to masses 4 or 5 inches in diameter. Many are elongated or subspherical, and some are flattened and stand vertically in the clay, suggesting their origin from the filling of fissures. They consist of clay, iron, and lime, and some of them are either hollow or have their interiors filled with calcareous clay. Here and there is a bed that consists of rounded lumps of hardened clay cemented together by ferruginous matter, which Cummins called a "peculiar conglomerate." It is suggested that this deposit may have had its origin in the breaking up of a thin bed of clay soon after deposition, by the action of running water or waves.[1]

Fossils.—Traces of plants appear locally in the sandstones, and in one place the large frond of a fern was obtained. David White, of the United States Geological Survey, has collected a considerable amount of plant material from these beds at two localities, one in Cassil Hollow, 2½ miles south of Fulda station, on the Wichita Valley Railway, and the other at the breaks of the Little Wichita, 4 miles southeast of that place. These collections include the following forms as provisionally identified. The species listed in italics are characteristic of the Permian.

Cassil Hollow:
- Pecopteris arborescens.
- Pecopteris hemitelioides.
- Pecopteris densifolia.
- Pecopteris grandifolia.
- Pecopteris mertensioides.
- Gigantopteris sp. (cf. nicotianifolia).
- Neuropteris (cf. lindahli).
- Aphlebia sp.
- *Tæniopteris multinervis.*

Cassil Hollow—Continued.
- *Annularia splicata.*
- Sphenophyllum? sp.
- *Sigillariostrobus hastatus.*
- *Walchia schneideri?*
- *Gomphostrobus bifidus.*
- Cardiocarpon n. sp.
- Carpolithes sp.
- Pelecypods.
- Estheria and fish scales.

[1] Merrill, G. P., Rocks, rock weathering, and soils, pp. 33, 34. Gardner, J. H., Jour. Geology, vol. 16, 1908, pp. 452–458.

Breaks of Little Wichita:
- Pecopteris hemitelioides.
- Pecopteris grandifolia.
- Pecopteris candolleana.
- Pecopteris tenuinervis.
- Diplothmema? sp.
- *Odontopteris fischeri?*
- *Odontopteris neuropteroides.*
- Neuropteris cordata.
- *Tæniopteris coriacea?*
- *Tæniopteris abnormis*
- *Tæniopteris n. sp.*
- *Sphenophyllum obovatum.*

Breaks of Little Wichita—Continued.
- Sigillaria sp. (leaf).
- *Gomphostrobus? sp.*
- Cordaites principalis.
- *Poacordaites cf. tenuifolius.*
- *Walchia piniformis.*
- *Aspidiopsis sp.*
- *Araucarites n. sp.*
- Cardiocarpon n. sp.
- Insect wings.
- Estheria.
- Anthracosia.
- Ostracoda and fish scales.

At Cassil Hollow the plants occur in a bed of blue and yellow laminated clay and sandy shales which crops out on the west side of a small tributary flowing into the north branch of Little Wichita River from the south. The following section was obtained at this place:

Section of Wichita formation at Cassil Hollow, 2½ miles south of Fulda, Tex.

	Feet.
1. Sandstones, thin bedded, shaly, with a fine exhibition of ripple marks. Represents the top of the section and grades into No. 2.	6
2. Blue and yellow laminated clay and sandy shale, grading horizontally into white shaly sandstones same as No. 1. The plants were found in a thin shale stratum near the middle of this division	6½
3. Hard bluish limestone which weathers to a brown. Apparently the equivalent of a limestone which outcrops on the Wichita nearly due north from this locality at the Bar X ranch. Contains an abundance of fragments of vertebrate remains, but all in such a comminuted condition as to be indeterminable	2
4. Blue clay shales	3
5. Red clay shales; same as No. 4, except in color	4
6. Gray sandy shales and sandstones to bottom of ravine	15
	36½

The limestone (No. 3) is made up of several layers, some of which are composed largely of fragmental remains of vertebrates, including plates, spines, fish teeth, etc. The stratification of the argillaceous and arenaceous sediments is very irregular, the sandstones and shales grading into each other both vertically and horizontally. Moreover, there is a monotonous likeness in both the sandstones and the shales throughout the area, which in the absence of persistent, clearly recognizable strata renders the correlation of beds, except within very narrow limits, practically impossible.

Some of the most prominent limestone divisions of the southern area persist, although in diminished thickness, as far north as Red River, perhaps farther. The limestones so well developed on Clear Creek, in the southwestern part of Throckmorton County, extend

northward through Seymour, are crossed by Wichita River about 3 miles east of the Seymour-Vernon road, and are last seen on Beaver Creek, in the eastern part of Wilbarger County. The transition of limestone into sandstone is well marked in an exposure in the bluffs of the Salt Fork of Brazos River, about a mile west of Spring Creek post office, in the northwest corner of Young County. A bed of limestone 3 feet thick and an overlying bed of blue shales 5 feet thick, both filled with fossils (chiefly *Myalina permiana*), are replaced within a distance of 200 yards by a light-colored cross-bedded calcareous sandstone having a maximum thickness of 15 feet. The transition is rather abrupt in appearance, but the sandstone contains much lime and also some fossils. Farther along the limestone reappears as before.

The limestones of the Wichita formation are for the most part highly fossiliferous, though in many of the beds good specimens are hard to obtain. A list of the invertebrate fossils obtained from these beds has been published elsewhere.[1] Collections of vertebrate remains have been made at various times in Archer and Baylor counties. A list of localities where the earlier collections were made is given by Cummins.[2] In many places the remains are found at the surface, having weathered out of the clays or lime beds. Certain strata, called the "bone beds," have furnished most of the material. A chalky friable limestone exposed in a railway cut just west of Mabelle station, in Baylor County, is filled with fragments of vertebrate remains allied to Eryops, mostly indeterminable. In a recent paper Williston[3] announces the discovery of a new genus and new species of amphibian allied to Eryops, which he names *Trematops milleri*. This specimen is said to have been found on Craddock's ranch, near Seymour. The figure of the skull given by Williston shows a close correspondence to one found by the writer in the friable limestone at the railway cut near Mabelle, which was unfortunately broken and in part lost before opportunity was given for identification. It seems probable that both came from nearly the same horizon.

Copper.—In places the bluish clays are copper bearing, but efforts to mine the deposits have not proved successful. The ore occurs in the form of small nodules in the clays and also as a replacement of pieces of wood. It is the copper oxide chiefly.

Oil.—Mention has been made of indications of the presence of oil in the Wichita formation in different localities. In 1907 the only producing field in the area was at Petrolia, in Clay County, where there were several producing wells. Later the Henrietta field, in the same county, was brought in. (See p. 47.) In a well put down for water

[1] Jour. Geology, vol. 19, 1911, pp. 131–134.
[2] Cummins, W. F., Jour. Geology, vol. 16, 1908, pp. 737–745.
[3] Williston, S. W., Jour. Geology, vol. 17, 1909, pp. 636–658.

at Electra a number of years ago by Mr. Waggoner oil was struck at about 600 feet. The well was extended to 1,790 feet. The water, most of which was found below 800 feet, rose within 15 feet of the top. The oil which covered the surface of the water was dipped out and used locally by the cattlemen, and also to burn, but no further attempt had been made to determine the existence of oil in commercial quantity. Most of the wells in this neighborhood show oil in small quantities. On January 17, 1911, the Producers Oil Co. brought in the second producing well on its No. 5 Waggoner tract, about 2 miles north of the town of Electra. This well yielded 50 barrels a day at a depth of 1,825 feet. From this time drilling was extremely active, particularly by the Producers Oil Co., the Clay County Oil Co., the Magnolia Co., and others. The oil is found in sands from 10 to 30 feet thick, lying at 580, 965, 1,035, and about 1,900 feet in depth. The wells yield from 50 to 1,200 barrels by natural flow. Natural-gas pressures are light, compared with those in the Petrolia and Henrietta pools. In September, 1911, the Electra field was credited with a production of 6,000 barrels a day.

A well put down in 1899 on the farm of Mr. Carmack, 1 mile northwest of Murray post office, in the southwestern part of Young County, struck gas at about 360 feet. In 1907 the escape from this well was sufficient to form a blaze from 1 to 2 feet high. As this well is located near the eastern border of the Wichita formation, it may be that the gas comes from the topmost beds of the Cisco formation.

Conditions of sedimentation.—The character of the sedimentation and the contents of the strata in the "Red Beds" area suggest that the region was a tidal flat or a low, swampy area subject to overflow and adjoining the open area which lay toward the south and west. This view is maintained by Case,[1] who states that "the whole formation seems to be very clearly the result of deposition, either in the form of a wide delta or in very shallow water." He adds, further, that "the remains which are found on or in the sand layers were evidently washed there by currents from a distant shore, and they are generally more or less imperfect, having been dispersed by the action of the current or by predatory animals, while those found in clay were evidently animals which mired down on wide mud flats or were drifted out on the surface of the stagnant lagoons."

The clays and the sandstones are separated in some places by unconformities which are considered by Case[2] to be the result of currents that eroded channels in the clay in which the sands were afterward deposited. They do not represent apparently any considerable time interval between the two deposits. Moreover, the conglomerates containing concretions of ferruginous clay are evidently

[1] Case, E. C., Bull. Am. Mus. Nat. Hist., vol. 23, 1907, pp. 659–664. [2] Idem, p. 661.

additional indications of transitory currents in an ordinarily quiet lagoon or over the tidal flats of a wide delta.

The red sediments evidently had their source in the degradation of the Wichita Mountains, which lie directly to the north of this region, in Oklahoma. These mountains were uplifted during or at the close of the Pennsylvanian epoch and are now, together with their accompanying elevations on the east, the Arbuckle Mountains, partly buried in the sediments they have furnished.[1]

The fact that in this region, as shown by their outcrop toward the east and by the strata penetrated in deep wells, the upper beds of the Cisco formation consist of sediments corresponding in character to those of the Wichita formation, suggests that mud flats may have characterized the closing stages of the Pennsylvanian epoch in this region.

Thickness.—In Shackelford County the thickness of the Wichita formation is estimated to be 1,000 to 1,200 feet. Two-thirds or more of the formation consists of blue clays and shales. Farther south, in the vicinity of Colorado River, limestones constitute the major part of the formation. To the north from Shackelford County the calcareous sediments diminish, and before reaching the Oklahoma border they practically disappear. No reliable estimate can be made of the thickness of the formation in this part of the region, though it is probably not less than 1,500 feet.

WATER RESOURCES.

As shown in the foregoing description of the geology of the region, the stratigraphy of the Wichita formation in the southern or "Albany" area presents a marked contrast to that in the northern or typical Wichita area.

In the southern area there are limestones at several horizons, some massive and others thin bedded, alternating with blue clay and sandy shales and sandstones. Though the shale beds greatly exceed the limestones in thickness, the latter, owing to their hardness, resist erosion better, and hence are found capping the elevations and constituting a series of parallel benches or escarpments that may be traced for long distances from the northeast toward the southwest. About two-thirds of the formation in Shackelford County consists of blue and gray clay shales, interbedded with which are some red clays and beds of sandstone. No good water-bearing bed is known to exist in the Wichita formation in the southern area. Locally the limestones and sandstones contain water, but it is usually saline. When followed northward the beds of the Wichita formation show marked diminution in the proportion of calcareous sediments and a corre-

[1] Case, E. C., op. cit., p. 664. Beede, J. W., Jour. Geology, vol. 17, 1909, p. 714.

sponding increase in sandy shales and sandstones. Moreover, the blue and gray colors of the shales and sandstones are in large part replaced by reds and browns, thus giving rise to the designation "Red Beds." In Archer, Clay, and Wichita counties the sandstones of the Wichita formation are locally porous and contain water, but owing to their transitional character and lack of persistency no correlation can be established between the sandstone beds of different localities. There are probably no persistent water-bearing beds in this region, the reservoirs being for the most part local. In Baylor and Wilbarger counties, where the upper beds appear, there are fewer sandstones and more limestones and shales, but no water-bearing beds of any importance. As a whole the Wichita formation is destitute of good water, but salt water is found at several horizons. A hole put down near Geraldine in Archer County struck water at 106, 298, 346, and 540 feet from the surface. The first water rose within 60 feet of the top and the others within 20 feet. All these waters were salt and unfit for use.

CLEAR FORK AND DOUBLE MOUNTAIN FORMATIONS.

GEOLOGY.

Overlying the Wichita formation conformably are red and blue clays, sandy shales, and sandstones, including deposits of gypsum and a few beds of earthy magnesian limestone. These rocks were subdivided by Cummins [1] into the Clear Fork and Double Mountain beds, but, as stated by that author, "no attempt has been made to determine a definite line of division between the two," and in view of the character of the sediments it is evident that the determination of such a line, if it can be made at all, will require much detailed work. Hill [2] proposed the term Brazos series to embrace "all those rocks of Texas, Oklahoma, Kansas, and New Mexico between the top of the conformable Coleman division of the Carboniferous beds below [and] the base of the unconformable Cretaceous above," but the suggestion has not been elsewhere adopted. According to Gould [3] these beds correspond to those in Oklahoma which he has termed in ascending order, the Enid, Blaine, Woodward, Greer, and Quartermaster formations.

In the lower beds red and blue clays predominate, but the upper beds are characterized by an increase in the proportion of arenaceous constituents and also of limestone and gypsum. The sandstones and limestones are friable and, together with the clays, yield readily to eroding agencies and supply a large amount of detritus to the streams, which are heavily charged with the red sediments brought down by their tributaries. In the lower beds the gypsum occurs as thin layers

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 401–402.
[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 100.
[3] Gould, C. N., Water-Supply Paper U. S. Geol. Survey No. 154, 1906, p. 17.

and lenses in the clays. Beds of massive gypsum 2 to 3 feet thick crop out in the hills south of Quanah. At Acme, where the material is quarried, the deposit is from 10 to 20 feet thick. In many places fibrous gypsum fills cracks which cut the alluvial clays in every direction.

The massive gypsum does not constitute persistent strata but thins out or is replaced horizontally by clays or limestones. J. J. Cyrus, a well driller of Quanah, states that the wells of that city derive their water from a porous limestone stratum at a depth of 75 feet and that no gypsum occurs in the overlying beds, which consist mostly of clay. A well put down a mile south of Quanah passed through a thick bed of gypsum at 40 to 65 feet and another at 75 to 83 feet, the latter apparently the equivalent of the limestone found in the city wells.

Except where overlain by fluviatile deposits of Quaternary age, the Clear Fork and Double Mountain formations constitute the surface rocks west of the Wichita formation as far as the escarpment that marks the eastern extension of the Triassic in Texas.

The age of these beds is generally recognized as Permian. Fossils are scarce and are confined chiefly to the limestones. The meager collections thus far made from these beds in Texas are not sufficient to warrant definite conclusions concerning them.

Cummins has assigned to these beds a total thickness of 3,900 feet, 1,900 feet to the Clear Fork and 2,000 feet to the Double Mountain. Only the lower beds of the formations are exposed in the Wichita region. Red gypsiferous shales and sands, with beds of gypsum and some limestones in the upper part, represent the formations as they appear here.

WATER RESOURCES.

Water is found in the shales and sandstones and to some extent in the limestones of the Clear Fork and Double Mountain formations. That which occurs in the shales and sandstones or near beds of gypsum is almost invariably strongly gypseous, but that in the limestone or closely related sandstones may be fairly good. Locally these waters yield supplies that are used for household purposes, but more generally they are available only for stock.

The character of the formations precludes the hope of finding potable water supplies at any general horizons.

CRETACEOUS SYSTEM.

COMANCHE SERIES.

East of the region the Carboniferous is overlain unconformably by the Cretaceous, patches of which also appear west and southwest of the region. Worn specimens of undoubtedly Cretaceous shells are found in the gravel escarpments along Wichita River in Knox and

Foard counties. The conclusion seems warranted, therefore, that the Cretaceous formerly extended over a large part if not the whole of the region. The only portion of the area, however, where Cretaceous rocks are now found in place is in the eastern part of Montague County, where the Trinity sand and the overlying Goodland limestone are recognized. The Trinity here consists of compact but easily eroded sand, usually called "pack sand," whose thickness ranges from a knife-edge at the border to 500 feet in the southeastern part of the county. Pebbles in varying amount are scattered through the formation, but only in the basal zone are they abundant enough to constitute a conglomerate. The Goodland limestone, which represents the Comanche Peak and Edwards limestones to the south, consists of a white limestone of dull or chalky texture and luster intersected with layers and seams of semicrystalline material. The thickness of the Goodland is about 15 to 20 feet.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

SEYMOUR FORMATION.

GEOLOGY.

Over the western part of the region, including Knox and Haskell counties, portions of Foard and Jones counties, and probably adjoining areas on the west, is a deposit of fine silts, sands, and gravels 10 to 50 feet thick except where removed by denuding agencies, to which the name Seymour beds was given by Cummins.[1] The sands are mostly red varying to white and are interstratified with lenses of gravel and red clay. In Knox County Brazos River and branches of the Wichita have removed this formation over wide areas and cut their valleys down into the underlying Clear Fork and Double Mountain formations. In the breaks of these streams the gravels are well exposed. On the south side of the valley of the South Fork of the Wichita, 5 miles north of Benjamin, the gravels with their accompanying sands and clays have a thickness of 25 feet. The pebbles are well-rounded and consist of quartz and crystalline rock, mostly of igneous origin. Silicified wood is common, as are also waterworn Gryphæa shells of Lower Cretaceous age. The character of the material suggests that it was derived from the Tertiary beds whose remnants outcrop in the escarpment of the Llano Estacado west of this area. Gould[2] has referred to the presence of waterworn Gryphæa shells of Lower Cretaceous age in the gravel beds at the immediate base of the Tertiary.

[1] Cummins, W. F., Fourth Ann. Rept. Texas Geol. Survey, 1893, pp. 181–190.
[2] Gould, C. N., Water-Supply Paper U. S. Geol. Survey No. 154, 1906, p. 29.

The area known or believed to be covered by this deposit is shown on the accompanying map (Pl. I). In the region between the North Fork of Wichita River and Pease River the flat interstream areas are underlain by 6 to 8 feet of fine dark-colored silt resting upon a bed of gravel 2 to 3 feet thick. These beds, which evidently belong to the Seymour formation, overlie the red Permian clays. The western limits of the Seymour formation are not known.

At several places east of the indicated boundary of the formation, patches of conglomerate were observed which may be related to the Seymour. Some of these patches cap the higher gravel terraces of the Brazos below Seymour. Half a mile south of Round Timber the river bluff, which is about 60 feet high, is capped by a bed of gravel and sand in which the pebbles consist chiefly of quartz and quartzite. This material is also spread over considerable areas in the vicinity of the river to the south, where it forms a thin veneer of sand and pebbles. In places it is consolidated into a fine conglomerate. The principal deposits of this character lie about 90 feet above the river. Pebbles of quartzite, quartz, and other siliceous rocks evidently derived from this bed are scattered over the surface of the lower terraces and along the river bed. Another locality where deposits of the same kind were observed is in the vicinity of Mabelle station, in Baylor County. The determination of the stratigraphic relations of these deposits and their connection, if any exists, with the Seymour formation must await more detailed observations with the aid of good maps. A valley conglomerate found on Concho River at San Angelo and elsewhere in Tom Green and Concho counties evidently corresponds to the formation here described. In that locality it is composed chiefly of fragments of chert derived from the Lower Cretaceous beds.

Cummins,[1] who first described the Seymour formation, asserted its Pleistocene age and gave a list of fossils collected from beds presumably of this horizon, though the correlation was not definitely made. Fossils other than the worn fragments of extraneous source already mentioned are not abundant. The fragments of bones of Pleistocene mammals occasionally found include Mastodon and Equus. At Knox City Mr. C. A. Benedict showed the writer the tooth of a mastodon which was found in a well at a depth of 40 feet, also a femur of the same species which was found in a ravine in the vicinity. Cummins [2] states that 14 miles east of Benjamin he collected fragments of the bones of Mastodon and Equus, among which was a femur 4 feet 2 inches in length.

Cummins considered these beds to have been formed in an inland lake which extended from Seymour westward to the range of gypsum hills bounding the formation on the west and which was drained

[1] Cummins, W. F., Fourth Ann. Rept. Texas Geol. Survey, 1892, pp. 181–190. [2] Idem, p. 182.

when Brazos River cut through the limestones at Seymour. The character and general relations of the sedimentation, however, suggests deposition by streams rather than in a lake. As shown by W. D. Johnson,[1] the heterogeneous distribution of clays, sands, silts, gravels, and conglomerates such as characterizes the Quaternary in the High Plains is the result of branching streams of desert habit. From Haskell north to the Brazos the formation has a thickness of 40 to 50 feet and is composed of about 30 feet of reddish calcareous silt or clay, with some sand and gravel, resting upon about 10 feet of sands and gravels. In the upper 1 or 2 feet the formation contains a large amount of lime which has partly consolidated to form an impure limestone or conglomerate. Calcareous deposits of this character, which have a wide distribution in arid regions, are known as caliche. The deposit is harder and more regular in structure at the top than below and is usually hidden from view by a slight covering of soil. The caliche surrounds and includes sand grains, gravels, and earthy materials, cementing them together, but does not usually become sufficiently hard to constitute a solid rock. Blake,[2] who has described such deposits in Arizona, states that "the formation is clearly the result of the upward capillary flow of calcareous water, induced by constant and rapid evaporation in a comparatively rainless region."

WATER RESOURCES.

An abundant supply of good water is usually found in the gravel beds that constitute the basal part of the Seymour formation. Where these lower beds are exposed by erosion under favorable conditions springs may be found, as at Haskell.

In the vicinity of streams which cut through the formation into the underlying Permian the supply is largely lost through seepage. In places in the upland areas also the beds are destitute of water, many wells extending through the gravels into the Permian beds called "Birdseye" by the drillers. The localization of the water in the gravels may be due to collection in basins in the unevenly eroded surface of the Permian.

The water is in general of fair quality and in places very good. It usually contains some gypsum, the amount differing with the locality.

RECENT SERIES.

GEOLOGY.

The stream valleys are floored throughout the greater part of their courses by gravels, sands, and silts which have been transported from higher levels to their present position by the present streams. The

[1] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 655.

[2] Blake, W. P., Trans. Am. Inst. Min. Eng., vol. 31, 1901, pp. 220–226.

valleys of the larger streams, such as Wichita, Brazos, and Pease rivers, are usually wide and along their sides may be found remnants of terraces to a height of 60 feet. These terrace deposits consist of gravel, sand, and silt of recent origin and are not to be confounded with the somewhat similar Pleistocene materials composing the Seymour formation and the apparently related high-level Pleistocene gravels and conglomerates mentioned on page 31. The bottom lands of Brazos and Wichita rivers are in places from 1 to 2 miles wide and are covered over large areas by sands that have been exposed during low stages of the river and on drying have drifted into mounds and ridges along the adjoining flats. Outside of the ordinary flood plains there are in places wide belts of excellent farming land, as seen on the Wichita north of Holliday and on the Brazos in southeastern Baylor County. Being derived for the greater part from the Permian red beds, the alluvial clays are in many places reddish in color.

In certain areas there are accumulations of sand of greater or less extent caused by the action of the wind. As to their mode of origin these sands are of two kinds—those blown from the stream channels, as already noted, and those derived from the disintegration of rocks in place and heaped up by the winds. The dunes of the first kind occur along the flood plains of practically all the larger streams and are composed of white or nearly white rather fine sand grains. For the most part they are barren of vegetation, but in places they are covered with a scanty growth of grass and bushes.

Sand hills of disintegration occur chiefly in the northwestern part of the region, in Wilbarger and Hardeman counties, and appear to be confined mostly to the areas underlain by the Seymour formation. They are best developed in the uplands north of Pease River, where they constitute ridges 6 to 8 miles long and 3 to 5 miles wide. Corresponding ridges of less extent occur along the south side of Pease River. Gould[1] states that the material of these upland sand hills has been derived largely from the disintegration of the underlying rocks. As the Tertiary and Pleistocene deposits are especially susceptible to the action of weathering agencies, sand hills of this character are most common in the regions to the west and north, where rocks of these ages are best developed. As the clay and silt present in the formations are removed by the action of water, the sand and the gravel remain behind and the finer materials are then rearranged by the action of the wind. As to the deposits of Pease River, however, the view has been advanced[2] that they were formed before the rivers had reached their present levels, and were blown out from the adjacent mud flats of the wide river or estuary,

[1] Gould, C. N., Water-Supply Paper U. S. Geol. Survey No. 154, 1906, p. 30.

[2] Lapham, J. E., and others, Soil survey of the Vernon area, Texas: Field Operations Bur. Soils for 1902, U. S. Dept. Agr., pp. 369, 372, 373.

and have been left behind by the recession of the streams. There can be little doubt that the sands were derived through the disintegration of the underlying rocks. It is not necessary to infer, however, the presence of a former large river or body of water from whose shores the sands were drifted inland. The disintegration of the rocks under the effects of weathering, the removal of the clay and silt through rainwash, and subsequent heaping of the sand by the winds would seem to offer an adequate explanation of the phenomena.

On Red River at Red Bluff, northeast of Vernon, there is said to be a deposit of volcanic ash,[1] the sole indication of igneous action so far as known within the area. It occurs near the top of the bluff and is overlain by fine sandy loam which is evidently of eolian origin and has apparently been modified more or less by the volcanic ash. The writer had no opportunity to examine this deposit, the source of which is wholly conjectural.

WATER RESOURCES.

In the vicinity of the main streams the alluvial sands and gravels usually contain ample supplies of good water. In the valleys of Wichita and Brazos rivers an abundance of good water is generally obtained at depths of 18 to 25 feet. Wells on the higher filled terraces have to go deeper, being from 40 to 60 feet deep, according to location.

In general the water in the valley deposits is of good quality, but locally, especially in the Permian area, it may be affected by the intrusion of waters from the adjoining beds.

SUMMARY AND RECOMMENDATIONS.

The present investigations have shown the occurrence of abundant supplies of underground water in this region, but almost invariably the water was found to be highly charged with mineral matter. This is especially true of most of the supplies obtained in beds belonging to the Carboniferous period. Exceptions are found in wells located near the outcrop of certain sandstone beds occurring near the contact of the Canyon and Cisco formations. Throughout a considerable area in the western part of the region good water is found in sands and gravels of Pleistocene age (Seymour formation) and is reached by wells from 20 to 50 feet in depth. Some of these beds furnish springs, as at Haskell. To these sources are to be added the shallow wells in the valleys, which derive their supplies from the alluvial deposits of Recent age.

Over a large part of this region the surface waters constitute the chief source of supply, both for domestic use and for stock. Away from the main valleys the rainfall is stored in surface tanks for use

[1] Lapham, J. E., op. cit., p. 369.

during the dry part of the year. Owing to the generally friable character of the rocks, the surface waters are charged with fine reddish silt which settles very slowly. The large amount of this red silt in the surface waters makes it desirable that the water be cleared in a settling tank before being used. Wichita Falls derives its supply from an artificial lake 7 miles long outside of the city. This water is decidedly red in color before it is filtered. An analysis of this water is given on page 54.

In view of the importance of surface waters as a source of domestic supply in this area, especial care should be exercised for the preservation of these supplies against pollution by animals or other means. "It is now universally recognized that the degree of prevalence of typhoid fever in a given community is a reliable measure of the extent to which sewage is an ingredient of its drinking water. The prevalence of typhoid in cities is a true index of the quality of the water supplies."[1]

Shallow wells and springs are especially susceptible to contamination from vaults, cesspools, broken sewers, slops thrown on the ground, pigpens, stables, and other sources of filth which readily passes into the ground. For the elimination of such contamination the location and care of a surface tank are important considerations. The tank should be placed at a considerable distance from any known source of contamination, in an open, clear drainage basin, preferably grass covered, from which stock and other agencies of pollution are rigorously excluded. Moreover, it should be frequently and carefully inspected to guard against the accidental access of contaminating substances.

Although the fine red silt so abundant in the waters of this region is not especially harmful to health, its presence in domestic supplies is objectionable and means should be employed for its removal. This may be accomplished in cities by the use of settling tanks in which the water is clarified before it enters the city mains. In smaller places recourse may be had to filters.

DESCRIPTION BY COUNTIES.

MONTAGUE COUNTY.

PHYSIOGRAPHY.

Montague County lies along the State boundary line. It has an area of 976 square miles and its population according to the census of 1910 was 25,123. The mean annual rainfall is 35 inches.

There are two drainage systems in the county separated by a divide which extends from the southwest corner northeastward past Bowie to St. Jo. The area on the north and west of this line is drained

[1] Ann. Rept. Connecticut State Board of Health, 1896, p. 21.

by several small northward-flowing tributaries of Red River, and that on the south and east by Clear Creek, Denton Fork, and other tributaries of Trinity River. Most of the streams which head in the sands near the divide carry perennial though small supplies of water. Those tributaries of Red River which lie wholly within the area of the Carboniferous rocks are for the most part wet-weather streams. In this area the relief is moderate and belongs to an advanced stage of dissection of a preexisting plain, the interstream areas being reduced to irregular hills and knobs of the more resistant sandstones. The altitude of the general plain surface is about 875 to 900 feet above sea level. Along the boundary of the Cretaceous the surface rises rather abruptly from 50 to 200 feet, with here and there irregular knobs and hills composed of the more resistant conglomeratic phases of the Cretaceous sands. Several elevations of this character, known as Cougar, Grindstone, Norton, and Rattlesnake mountains, exist near and to the southwest of Bowie. Queens Peak is a rather prominent elevation about 4 miles north of Bowie, and to the northeast of it are the Belknap Hills. Southeast of this range of hills is a belt of rolling sands, which toward the northeast is much dissected by the streams flowing northward into Red River. The southeastern boundary of this sandy area is marked by an escarpment, and sandstone knobs are noticeable features of the landscape. One of the most prominent elevations is Gordon Mountain, a narrow limestone-capped ridge 4 or 5 miles long just north of St. Jo.

GEOLOGY.

The geology of the county is simple. Underlying the whole area are rocks of Carboniferous age, and resting unconformably upon these in the southeastern part of the county are sands and limestones belonging to the Cretaceous. The Carboniferous rocks lie nearly horizontal or dip toward the west; the Cretaceous rocks dip southeastward. The boundary of the Cretaceous crosses the south line of the county about 6 miles east of the southwest corner and passes northward through Bowie and thence northeastward to the northeast corner of the county. The boundary as thus delineated is irregular and serrate, as a result of the erosion of the formations which once undoubtedly covered the whole of the county.

The Carboniferous rocks which constitute the surface formation over the northwest half of the county belong to the upper part of the Cisco formation and consist of variegated red, brown, and blue sandy shales and shaly sandstones that grade horizontally and vertically into cross-bedded yellowish and white sandstones. The sandstones are locally conglomeratic and, owing to their greater resistance to erosion, in places cap elevations or project in ledges above the general surface. Coal which Cummins regards as his coal seam

No. 7 crops out about 4 miles southwest of Bowie, and attempts were at one time made to mine it at this locality. A tunnel 400 feet long was driven into the side of the hill, and 1½ miles farther north shafts were put down to coal, which was reached at a depth of 150 feet. In all the shafts water was encountered in the sandstone above the coal. The following section was made by Cummins[1] at the mouth of the tunnel:

Section at mouth of tunnel near Bowie, Tex.

	Ft.	In.
Sandstone	6	
Clay	20	
Sandstone	15	
Slate	3	
Coal	2	
Slate		6
Coal	1	4
Fire clay		10
	48	2

The dip of the coal, according to Cummins, is to the northwest. The coal shaft of the Max Edser mine, now abandoned, is reported by the owner, C. H. Boedeker, of Bowie, to be 160 feet deep and the coal to be 48 inches thick, including a slate seam of about 4 inches. A hole drilled 200 feet deeper failed to show other beds of coal. The records of this drill hole were not obtainable. Six miles northwest of Bowie, on the north side of the track of the Fort Worth & Denver City Railway, is an abandoned coal shaft which is now filled with water within 30 feet of the top. This shaft is reported to be 412 feet deep, but no reliable data concerning it could be obtained. The dump shows a considerable amount of black carbonaceous shales as the last material taken out. The only other occurrence of coal in the county of which information is at hand is in a well 4 miles north of Bowie and 1 mile east of the Peak schoolhouse. The well starts in sandstone of the Cisco formation and is said to have reached coal at 62 feet. The seam is 6 inches thick. When the coal was reached, water was encountered which probably came from the overlying sandstone. It rose within 25 feet of the top of the well. On the assumption that the coal in these several localities belongs to the same seam, which is probable, it is estimated that the northwest dip of the beds is about 70 feet to the mile.

The southeast half of the county is underlain by sands and conglomerates belonging to the lower division (Trinity sand) of the Cretaceous. Overlying these sands and capping the higher elevations in the eastern part of the county is a limestone which in Oklahoma is known as the Goodland limestone. It represents the forma-

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, p. 508.

tions to the south called the Comanche Peak and Edwards limestones. The Trinity formation in Montague County consists of compact but easily eroded sand, usually called "pack sand," whose thickness ranges from a knife-edge at the borders to 500 feet in the southeastern part of the county. Pebbles in varying amount are scattered through the formation, but only in the basal zone are they abundant enough to constitute a conglomerate. In this zone the pebbly beds are locally of considerable thickness and are in some places loosely consolidated and in others indurated to form a hard, resistant rock. The Belknap Hills, Queens Peak, Brushy Mound, and other elevations along the border of the Cretaceous area owe their relief to the resistance to erosion offered by these beds. As shown by Hill [1] the Goodland limestone is exposed along the western border scarp of the Grand Prairie and in the numerous inlying areas of the valleys of the many tributaries of the Trinity and the streams which score its surface. It is a white limestone of dull or chalky texture and luster, intersected with layers and seams of semicrystalline material. The thickness of the limestone is about 15 to 20 feet.

WATER CONDITIONS.

WELLS.

CARBONIFEROUS AREA.

Most of the water supply of the county is derived from shallow wells. In the Carboniferous area water is found in the sandstones at depths varying from 30 to 250 feet, and throughout a large part of the county water may be reached at 20 to 50 feet. The water in these shallow wells is usually hard and often impregnated with objectionable salts. The supply is rather scanty, and it is necessary in some areas to go deeper for satisfactory quantities. Other horizons are reached at depths ranging from 50 to 200 feet, but owing to the varying character of the formations no correlation can be made between the wells at different horizons.

At Nocona water is found in the northeastern and southwestern parts of the town at 20 to 40 feet in depth. The wells in a belt extending through the town from northwest to southeast are reported to be from 100 to 250 feet deep. The most common depth is 100 to 130 feet. In the shallow wells the water stands about 18 feet below the surface and in the deep wells, according to the principal of the public schools, it stands at about 80 feet. A well put down by G. A. Stafford for Carmichael Bros. yields when pumped 7,000 gallons a day. It is cased with 6-inch pipe for 217 feet and with 4-inch pipe for the remaining 42 feet. The water varies in

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 217.

quality, being good in some wells and poor in others. In general, the water from the deeper wells is soft and that from the shallow wells is hard.

About 2½ miles north of McCallums, on the farm of John Morris, a well 134 feet deep was put down in 1892. For a time the water was fairly good, but later it became so highly charged with mineral salts that it could not be used. Another well 84 yards to the northeast struck water at 137 feet. The record of this well, given by Mr. Morris, is as follows:

Record of well on farm of John Morris, near McCallums, Tex.

	Feet.
1. Surface sand and clay	28
2. Soft sandstone	36
3. Black clay	8
4. Mixed clay, sand, and lime, in part concretionary	15
5. Pack sand	40
6. Dark-red clay, almost black	6
7. Hard rock	4
8. Sand with gravel and water.	

Nos. 1 to 5 represent the basal portion of the Trinity sand; Nos. 6 to 8 belong to the Cisco formation of the Carboniferous. The water in this well is fairly good.

At Belcherville the public well is 165½ feet deep; the water, which is of fairly good quality, rose rapidly, when the bits were drawn, within 90 feet from the surface. The water of other shallow wells in the vicinity is said to differ considerably in quality, but no analyses have been made. In 1895 a well put down by John Witherspoon was extended to a depth of 961 feet. William M. Cassel, the foreman in charge of the work, makes the following statement concerning it:

> The principal water-bearing stratum was reached at 600 feet. Several other water-bearing strata were passed through above this, but they were cased off. The water from the 600-foot level rose within 100 feet of the surface. Deposits of coal, "granite," sulphur, and salt were passed through, but nothing definite is now known concerning them. Analysis was made of the water, but this has been lost. It is known, however, that the water was highly charged with salt and sulphur.

At Ringgold water is obtained at depths of 20 to 200 feet. The water in this vicinity is predominantly brackish. Cisterns constitute the main source of supply, the statement being made by residents that there is "no good water outside of cisterns."

In the vicinity of Stoneburg water is found in shallow wells at depths of 25 to 40 feet. In these wells the water rises within 10 to 20 feet from the surface. At depths varying from 72 to 160 feet water is struck which supplies flowing wells in favorably situated localities. A. S. Jamieson's well, located 200 yards south of the Chicago, Rock Island & Gulf Railway Station, is 160 feet deep. The water flows

out in a small stream and is said to be fairly good for general use, but hard on boilers. The elevation of the top of the well is about 930 feet above sea level. The drill is reported to have passed through 5 to 6 feet of soil, about 8 feet of white sand containing plenty of soft water, and blue shale and sandy clay with alternating beds of sandstone down to about 145½ feet. Water was found in a clay or quicksand formation underlying a "honeycomb" rock, probably a sandstone. The fine material pumps up and chokes the well.

About 200 yards south of the Jamieson well is one put down by the Chicago, Rock Island & Gulf Railway Co., the following record of which was furnished by Mr. Paul Friesen, acting chief engineer:

Record of Chicago, Rock Island & Gulf Railway Co.'s well at Stoneburg, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface material	2	2
Quicksand with water	11	13
Clay	11	24
Blue sandrock and slate	34	58
Sandrock	12	70
Red clay	10	80
Clay and slate	26	106
Sandrock and some water	12	118
Red clay	11	129
Hard sandrock	13	142
Quicksand with water, which flows out at top	3	145
Hard honeycomb rock	½	145½

The water was struck at 143 feet. The well flows at the rate of 1,000 gallons a day and affords about 17,000 gallons a day when pumped. The rocks penetrated in this well belong wholly to the Cisco formation. At this place the elevation of the water beds is approximately 890 feet above sea level.

About 1¼ miles south of the Stoneburg station a flowing well was obtained by James Anderson at a depth of 98½ feet. The exact elevation of the top of this well is not known, but an estimate based on the contour map of the region indicates that the water is reached here at a level 40 feet higher than at the station.

Three-fourths of a mile farther south W. T. Small has a flowing well 72½ feet deep. The top of the well is possibly 10 feet lower than that of the railway well. It is estimated that water is reached in this well at about 835 feet above sea level, or 63 feet higher than at Stoneburg. It seems probable that all these wells terminate in the same stratum, which has a northward inclination of about 32 feet to the mile. As the real dip of the strata is to the northwest, the data here given harmonize with others showing the dip to be about 70 feet to the mile (p. 37). The character of the water from the Small well is shown by the following analysis, by Walton Van Winkle, of the United States Geological Survey:

Analysis of water from well of W. T. Small, near Stoneburg, Tex.

[Parts per million.]

Silica (SiO_2)	4.8
Iron (Fe)	.08
Calcium (Ca)	32
Magnesium (Mg)	8.2
Sodium (Na) and potassium (K)	121
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	365
Sulphate radicle (SO_4)	49
Chlorine (Cl)	61
Nitrate radicle (NO_3)	1.06
Total solids	457

This analysis shows that the water comes within the limit of ordinary river water in the proportion of calcium and magnesium, but is higher in chlorine and bicarbonates. It is used for household purposes and for stock and would apparently do well in boilers.

Water from the well of C. M. Chase, near the Small well, May, 1907, gave the following results according to the same analyst:

Analysis of water from well of C. M. Chase, near Stoneburg, Tex.

[Parts per million.]

Silica (SiO_2)	7.2
Iron (Fe)	.3
Calcium (Ca)	6.4
Magnesium (Mg)	10
Sodium (Na) and potassium (K)	174
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	381
Sulphate radicle (SO_4)	25
Chlorine (Cl)	36
Nitrate radicle (NO_3)	.97
Total solids	458

This water, although slightly higher in alkalies and lower in chlorine, corresponds fairly with that from the Small well. The flow is small but constant.

About 3½ miles east of Stoneburg, on the farm of C. H. Bacon, are two wells 113 and 96 feet deep. Both are flowing wells and when cased up the water stands 2 feet above the level of the ground. These wells are located near the border of the Cretaceous at the northwest base of the Belknap Hills. Their flow is small but regular. A bucketful taken from the basin will cause the flow to cease for a few seconds.

Bowie is situated near the southwest corner of the county, just within the border of the Cretaceous area. The thickness of the Trinity sand here, as shown by well records, is about 40 feet. The increase in thickness toward the east is rapid and in that part of the

county, so far as known, no wells extend through the Trinity sand. There are several deep wells in the town which extend through the Trinity into the underlying Cisco formation. The Bowie ice plant and the Bowie Oil Co. each have wells about 500 feet deep. The old well of the city waterworks derived its supply from a depth of 540 feet, but this proving insufficient, a new well was finished in 1907 at a depth of 640 feet and gives, according to Mayor C. H. Boedeker, "an inexhaustible supply of good water."

Its record is as follows:

Record of new well of city waterworks, Bowie, Tex.

[Elevation at top of well, 1,145 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Trinity sand (Cretaceous):		
1. Soft sandy soil with some gravel and water	30	30
2. Hard yellow clay	10	40
Cisco (Carboniferous):		
3. Hard sandstone	38	78
4. Hard soapstone rock	18	96
5. Slate; traces of coal	4	100
6. Hard soapstone or fire clay	8	108
7. Conglomerate (concrete rock)	132	240
8. Shale	11	251
9. Hard concrete, similar to No. 7	54	305
10. Gritty shale, "hardpan"	75	380
11. Hard concrete rock, difficult to drill	55	435
12. Red shale	13	448
13. Sandstone	32	480
14. Red shale	18	498
15. Hard shale, "hardpan"	12	510
16. Sandstone	9	519
17. Sand with water	9	528
18. Sandstone	4	532
19. Soapstone, shale, and slate	69	601
20. Sand with water	19	620

The water in bed No. 20 stands 180 feet below the top when pumped. This water was analyzed by Walton Van Winkle in March, 1907, with the following results:

Analyses of water from new city well, Bowie, Tex.

[Parts per million.]

Silica (SiO_2)	5.4
Iron (Fe)	.3
Calcium (Ca)	21
Magnesium (Mg)	9.5
Sodium (Na) and potassium (K)	772
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	382
Sulphate radicle (SO_4)	129
Chlorine (Cl)	972
Nitrate radicle (NO_3)	1.86
Total solids	2,119

This is a soft water high in chlorine and alkalies.

CRETACEOUS AREA.

In the Cretaceous area water may be obtained as a rule at depths of 20 to 150 feet. Most of the wells are from 30 to 80 feet deep. The differences in the depths of the wells are due in part to the character of the relief as related to the position of the water table, and in part to the changes in the character of the beds themselves, the sands in places containing more clay or being finer grained and more compact. For the most part water for domestic purposes is obtained from shallow wells. There are no deep wells within the area except near the border, as at Bowie (p. 42). At that place the deep wells find water in the underlying Cisco formation. The water in the Trinity sand is generally mineralized to a greater or less extent, and hence it is in many places necessary to rely upon cisterns both for domestic use and for stock. Owing to the compactness of the sands, the movement of the ground water in them is slow and generally the supply from these beds is small. E. B. Sizemore put down a well at Newharp, near the southeast corner of the county, and says that it is 129 feet deep, is nonflowing, and furnishes about 10,000 gallons a day. The water is used for running a large gin. The drill passed through the following beds, according to Mr. Sizemore:

Record of well of E. B. Sizemore at Newharp, Tex.

	Thickness.	Depth.
	Ft. in.	*Ft. in.*
1. Soil	4	2
2. Packsand or sandrock	40	44
3. Blue clay and struck water		
4. Packsand; water at 80 feet	41	85
5. Red bottom clay	2	87
6. Unrecorded	27	112
7. Stone coal	2	112 2
8. Sandstone	26 10	129

The beds to and including No. 4 are Trinity and those below No. 4 are evidently Cisco. Water is reported from the Trinity at 44 and 80 feet. No mention is made of water in the Cisco formation.

Four miles southeast of Nocona is a well 235 feet deep. The record of this well is not available, but it was learned that the drill passed through sandstone, red sandy shale with some hard rock, and, near the bottom, soft sand with water which rose within 60 feet of the top. This well is situated on a hill near the border of the Trinity sand. The water is soft and evidently comes from the underlying Cisco. The elevation at the top of the well is 1,050 feet above sea level. About a quarter of a mile northeast of this well is an old well, 73 feet deep, in which the water is hard. The top of the old well is about 20 feet lower than that of the other well, and the water in it is evidently in the basal part of the Trinity.

Montague, the county seat, is located on the Trinity sand, in which water is found at depths of 60 to 80 feet. The water contains a considerable but varying amount of mineral matter, wells near together showing marked differences. The courthouse well is 60 feet deep, as is also the parsonage well, located 600 feet farther south. The "old well" on the square, which is 80 feet deep, contains somewhat better water than either of the other two. About 500 feet west of the courthouse well is the "wagon house" well, which is about 40 feet deep. All these wells derive their supply from the Trinity. Analyses of the waters are given below.

Analyses of water from wells at Montague, Tex.

[Parts per million. W. M. Barr, analyst. Samples collected December, 1906.]

	Courthouse well.	Parsonage well.	Wagon house well.
Silica (SiO_2)	19	26	21
Iron (Fe)	Tr.	3.6	.05
Calcium (Ca)	327	96	270
Magnesium (Mg)	74	27	29
Sodium (Na) and potassium (K)	284	26	88
Carbonates (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	442	334	249
Sulphate radicle (SO_4)	262	54	104
Chlorine (Cl)	653	43	186
Nitrate radicle (NO_3)	102	Tr.	334
Total solids	2,075	446	1,272

Owing to the large proportion of iron the water from the parsonage well has a disagreeable taste and is not used. The porous character of the sandy formation underlying the town is decidedly favorable to the contamination of the ground waters by sewage.

SPRINGS.

Springs in Montague County are few and are for the most part small and unimportant. Most of them are in the Trinity sand area and along its border. Near Gladys and Forestburg are small springs and one near Forestburg is reported as yielding a "never-failing" supply of warm water. The springs supplying cold water usually run dry in summer. The water of these springs is hard. A few soft-water springs occur in the Cisco area, notably near Stoneburg and Ringgold. Their flow is small.

CLAY COUNTY.

PHYSIOGRAPHY.

Clay County has an area of 1,250 square miles, and its population in 1910 was 17,043. The mean annual rainfall is 32 inches. The county is drained chiefly by Little Wichita River, which flows north-

eastward through the middle of the county into Red River. The Wichita flows through the northwestern part of the county.

The surface is for the most part a timberless, moderately dissected plain. The soils consist of fine sand or sandy clays derived from the underlying sandstones and shales.

GEOLOGY.

The rocks outcropping in this county consist of white, brown, and red sandstones and red sandy shales, the colors in places varying to blue. Except in a small area of the Cisco formation in the southeastern part of the county the indurated rocks belong to the Wichita formation. Owing to their apparently conformable relations, their lithologic correspondence, and the lack of good exposures the boundary between the formations is nowhere clearly defined and can therefore be indicated only approximately.

The Cisco consists of sandstones and shales, mostly red, the sandstones appearing here and there over the plain surface in outcropping benches and low escarpments. Just over the line in Jack County, near Postoak, the upper part of the formation consists of 25 to 30 feet of conglomerate overlying red shales grading into sandy beds. The conglomerate is composed of partly worn subangular fragments of siliceous limestone and chert in a matrix of sand. In places it grades into brown ferruginous sandstone. In general the fragments are of the size of peas or navy beans, but locally they are larger or smaller. This conglomerate is apparently identical with that seen at Graham, in Young County, and it is believed to represent about the same horizon. No exposures of this bed were seen in Clay County, but the indications are that it is present in the southeast corner of the county and across the boundary in Montague County.

In the area underlain by the Wichita formation the exposures are mostly low ledges of sandstone scattered over the plain capping low elevations and stream slopes. The main part of these ledges is composed of red and variegated shales with intercalated lenses of sandstones. The thickness of the Wichita in Clay County is not known.

A short distance west of Henrietta copper is said to occur in the red sandstones and shales, chiefly in the shales. The ore, which consists of small nodules disseminated through the shales, according to reports, assays about 60 per cent of copper.

At Petrolia oil is found at depths of 278, 358, 438, 650, and 750 to 800 feet. The principal supply is derived from beds at the 278-foot and 438-foot horizons. The deepest bed supplies one well only. The first 10 wells in this district were put down by J. L. Jackson, of Jackson & Moore, of Wichita Falls, from whom the following record was obtained:

Record of oil wells in the Petrolia oil field.

[Elevation of top of wells, 1,025 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
1. Red shale, with a few feet of soil on top	100	100
2. Sand, with showing of oil	5	105
3. Red shale	75	180
4. Sand, with trace of oil	8	188
5. Red shale	75	263
6. Blue shale	15	278
7. Oil sand	15	293
8. Red shale	40	333
9. Blue shale	10	343
10. Sand, with some oil	15	358
11. Red shale	72	430
12. Blue shale	8	438
13. Sand, with oil	10	448

The first oil produced in the field came from the sand (No. 7) at 278 feet. When first put down, in 1903, the wells produced from 5 to 55 barrels a day; in 1907 the wells had declined to about 3 barrels a day. Later wells were extended to the sand at 448 feet, from which in 1907 the chief production was obtained. The oil from the lower sand is said to have a higher specific gravity than that from the upper sand.

Well No. 1 of the Corsicana Petroleum Co., of Corsicana, Tex., is located on the farm of Byers Bros. It is the deepest hole that had been put down in the field at the time when this investigation was made (1907). No oil or gas was found. The well is located about 3 miles northeast of Petrolia. It is cased with 6-inch pipe down to a depth of 367 feet and with 4-inch pipe to 1,002 feet. No notice was taken of water horizons. The following record was made by M. W. Bahan:

Record of well No. 1 of Corsicana Petroleum Co., near Petrolia, Tex.

[Elevation of top of well, about 1,025 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
1. Sand, sandstone, and clay	243	243
2. White sand, with small show of oil	6	249
3. Sandrock and clay	118	367
4. Sandrock and red shale	629	996
5. Sandrock and shale, with some sand (indications of gas)	9	1,005
6. Hard red rock	49	1,054
7. Hard sandrock	5	1,059
8. Hard red rock	33	1,092
9. Soft shale	51	1,143
10. Red shale	157	1,300

Neither of the records obtained gives any satisfactory evidence as to the location of the plane of separation between the Wichita and the Cisco formations. From Mr. James Darling it was learned that in some of the wells a conglomerate bed 12 feet thick was found at a depth of 490 feet. If this is upper Cisco, then the Wichita is probably

penetrated at a depth of 263 feet. The major part of the development of the field is in an area less than 3 miles in diameter, the center of which is about 1¾ miles southeast of Petrolia.

WATER CONDITIONS.

In the valley of Red River, at the north end of the county, plentiful supplies of potable water are found at a depth of 25 feet. Along the bluffs bordering the valley there are numerous small springs, but no deep wells are reported from this or any other part of the county, except as already mentioned.

In the upland areas water is found in the sandstones at depths varying from 30 to 130 feet. Shallow wells and cisterns furnish water for domestic use. Water for stock is obtained from artificial pools and to some extent from wells.

At Henrietta the wells are from 25 to 40 feet deep. A few miles out of town it is necessary to sink to a depth of 72 to 100 feet. The town supply is obtained from two wells located in a draw about three-fourths of a mile south of town. The supply is insufficient to meet the demand during portions of the year when the gins are in operation, and it is then supplemented by pumping from a surface tank near by. At the time of the writer's visit the surface of this tank was covered by slime and the water appeared to be unfit to drink. No record is kept as to the amount of tank water that is mixed with that of the wells in the mains. If a sufficient quantity of water can not be obtained by sinking other wells, steps should be taken to construct a tank in a location where it will be free from the danger of contamination. In some wells the water is brackish or alkaline; in others it is fairly good.

In the vicinity of Bellevue two water horizons are reported, the first at 30 to 35 feet and the second at 100 to 110 feet. The water in the shallow wells is soft and that in the deeper wells is hard. There is no public supply of water for the town of Bellevue, but a supply may be obtained from a lake in the vicinity covering 40 acres, which is fed by underground springs and is said to be practically inexhaustible.

Since 1907, when this field was examined, there has been a marked development in oil operations, especially in the vicinity of Electra, in Wichita County. The region including Clay and Wichita counties is said to be now producing 10,000 barrels of oil a day.[1] The principal oil area is in Wichita County and the principal gas area is in Clay County. According to the report cited, which is based on investigations made by J. A. Udden, the oil and gas have accumulated in lentils of sand that were originally bars and beaches in the Cisco and Wichita seas. "The Henrietta-Petrolia gas and oil field is an irregular elongated dome about 200 feet high, having an area of 6 or 7 square

[1] Press letter, Bur. Econ. Geology, Univ. Texas, W. B. Phillips, director, Mar. 15, 1912.

miles. It is about twice as long as broad, and the longer axis extends in a west-northwest and east-southeast direction." The author quoted considers that the oil and gas bearing sands of this field occur in the upper part of the Cisco formation or the lower part of the Wichita formation, and that they are contemporary in deposition with the coal beds occurring at this horizon farther south. This places the plane of separation between the Cisco and Wichita formations here at 700 to 900 feet from the surface, a position which accords with the writer's view.

Two logs of borings kindly furnished by Mr. Udden are given below. In each of these borings six water-bearing sands were noted. In the Byers well No. 3 a fresh-water sand was found at 137–172 feet which was not encountered in the Myers farm well No. 1, and the latter well shows a water sand at 955-975 feet which did not appear in the former. The correlation of the other water beds seems to be fairly well established, but it should be remembered that in formations of such irregularity in lithologic character the determinations are provisional only. There is probably little doubt that all the waters except that at 137 to 172 feet in the Byers well were saline.

Log of Myers farm well No. 1, near Henrietta, Tex.

Elevation of Henrietta, 915 feet above sea level (Weather Bureau). Began drilling May 27, 1909. Finished drilling December 31, 1909. Set 176 feet of 12½-inch casing, 589 feet of 10-inch casing, 1,310 feet of 8-inch casing, 1,924 feet of 6-inch casing. All pipe pulled when well was abandoned.

	Thickness.	Depth.
	Feet.	*Feet.*
Red mud	280	280
Gray water sand (B)	20	300
Red cave	15	415
Gray slate	10	425
Red cave	75	500
White water sand (C)	25	525
Red cave	10	535
Broken sand	15	550
Gray salt sand	10	565
Red cave	10	575
White slate	15	590
Red and white, mixed	25	615
Salt-water sand (D)	21	636
Red cave	19	655
White slate	20	675
Red and blue mud	10	685
White slate	15	700
Red cave	5	705
White slate	5	710
White salt sand	25	735
Broken gray sand	10	745
Hard brown sand, oil	10	755
Loose white sand	45	800
Broken gray sand	10	810
Red cave	10	820
White slate and shell	5	825
Red cave	20	845
Gray shells	10	855
Red cave	10	865
White sand	10	875
Water sand (E)	10	885
Slate	10	890
Dark-gray shells	10	900
Light slate	10	910

Log of Myers farm well No. 1, near Henrietta, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Red bed	15	925
White sand	15	940
Red rock	15	955
Gray water sand (X)?	20	975
Blue slate	5	980
Red rock	25	1,005
Blue slate	5	1,010
White salt sand	10	1,020
Red marl; streaks of blue shale	10	1,030
Light-gray sand	10	1,040
Red marl	15	1,055
Dry gray sand	5	1,060
Red marl	25	1,085
White salt sand	15	1,100
Broken sand	15	1,115
Soft white sand	10	1,125
Broken sand	15	1,140
Blue slate	10	1,150
Dry white sand	5	1,155
Dark-blue slate	25	1,180
Sand; streaks of shale	20	1,200
Red marl	25	1,225
Gray sand	5	1,230
Red marl	40	1,270
Brown shells	10	1,280
Red marl	50	1,330
Brown sand (F)?	20	1,350
Blue slate	30	1,380
Red marl; streaks of white sand	90	1,470
Brown slate	25	1,495
White slate	11	1,606
White salt sand	22	1,628
Blue shale	20	1,648
White salt sand	15	1,663
Blue shale	37	1,700
White shale	15	1,715
White salt sand	12	1,727
Black gumbo	10	1,737
Gray sand	7	1,744
Blue shale	46	1,790
Sand; streaks of blue shale	20	1,810
White salt sand	10	1,820
Blue shale	20	1,840
Gray sand	10	1,850
Blue slate; streaks of black slate	80	1,930
Blue slate	243	2,173
Gray salt sand	7	2,180

Log of Byers well No. 3, Petrolia field, Tex.

Elevation of Petrolia, 967 feet above sea level at station. Began drilling October 20, 1908. Finished well April 14, 1909. Set 127 feet of 12-inch casing, 697 feet of 10-inch casing, 1,466 feet of 8-inch casing, 1,789 feet of 6-inch casing, and 1,959 feet of 4½-inch casing.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	75	75
Sand shell	2	77
Blue mud	20	97
Red cave	40	137
Big fresh-water sand (A)	35	172
Red and blue mix	35	207
Red mud	20	227
Dry sand	15	242
Sandy blue mud	20	262
Red mud	40	302
Water sand (B)	8	310
Red and blue rock	175	485
Sand	8	493
Shale	4	497

Log of Byers well No. 3, Petrolia field, Tex.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand; salt water (C)	50	547
Blue gumbo and gravel	8	555
Red gumbo and gravel	40	590
Blue shale	10	600
Very dark red shale	45	645
Blue shale	5	650
Dark-red shale	28	678
White shale	12	690
Water sand (D)	38	728
Water shale	3	731
Red and blue mix	50	781
Blue shale	91	871
Very red shale	50	921
Broken sand	5	926
Red shale	15	941
Black slate	64	1,006
Red and blue mix	45	1,051
Red shale	25	1,076
Blue shale	17	1,093
Water sand (E)	35	1,128
Shale hard	20	1,148
Sand	15	1,163
Blue shale	38	1,201
"Duke's Mixture"	10	1,211
Sky-blue shale	10	1,221
Brown gritty shale	10	1,231
Rotten sand	25	1,256
Blue shale, sand shells	60	1,316
Dark-red shale	15	1,331
Water sand (F)	30	1,361
Blue shale	8	1,369
Sand	6	1,375
Dark-blue shale	4	1,379
Sand	2	1,381
Blue shale	24	1,405
Dark sand	15	1,420
Dark-blue shale	36	1,456
Very hard dark-blue shale	1	1,457
Blue shale	43	1,500
Hard black sand	2	1,502
Dark-red shale	8	1,510
Dark sand	8	1,518
Dark-blue shale	7	1,525
Blue lime	4	1,529
Sky-blue shale	85	1,614
Gas sand	1	1,615
Black shale	30	1,645
Fine dark sand	17	1,662
Dark-blue shale	27	1,789
Hard shell lime	1	1,790
Shale	16	1,806
Soft sand (fine oil)	11	1,817
Brown shale	2	1,819
Black shale	4	1,823
Light-blue shale	37	1,860
Oil sand	27	1,887
Black slate	62	1,959
Sand	5	1,964
Blue shale	10	1,974
Big salt sand, "Gulf of Mexico"	536	2,510
Abandoned.		

WICHITA COUNTY.

PHYSIOGRAPHY.

Wichita County has an area of 606 square miles, and its population according to the census of 1910 was 16,094. The mean annual rainfall is 25 inches.

The surface is an eastward-sloping plain incised on the south by Wichita River and its tributaries and on the north by a few insignifi-

cant tributaries of Red River. The general surface rises toward the west or northwest at the rate of about 7 feet to the mile. The main valley of Wichita River is a wide alluvial plain about 60 feet below the general surface. The river flows in a narrow channel sunk 25 feet below the valley bottom. According to the railway profiles the station at Wichita Falls, the lowest point in the valley, has an elevation of 946 feet above sea level. The stations at Iowa Park and Electra are on the plateau level and have elevations, respectively, of 1,037 and 1,229 feet.

GEOLOGY.

The rocks exposed at the surface in Wichita County belong wholly to the Wichita or lowermost formation of the Permian series. Exposures within the county are not abundant and are confined chiefly to the gullies and ravines along the sides of the Wichita Valley. As noted elsewhere the rocks consist of red and variegated shales and sandstones. The shales are generally sandy and in places contain an abundance of ferruginous concretions. The sandstones are of varying hardness. In places the strata are 5 to 10 feet thick and grade horizontally and vertically into the associated shales. Owing to the nonpersistent character of the sandstones it is difficult to correlate rocks of different localities. With the disappearance of a sandstone in its horizontal extension, new beds of exactly similar constitution appear at higher or lower levels, and these in turn give way to others. About 3 miles west of Wichita Falls the following section was obtained in the breaks of the Wichita:

Section near Wichita Falls, Tex.

	Feet.
1. Red clay filled with ferruginous concretions	10
2. Red and variegated sandstones, cross-bedded, and for the most part in thin layers	8
3. Red nodular clays to bottom of ravine	20

This bed of sandstone (No. 2) can be traced three-fourths of a mile to the west and then disappears below the bottom of the valley. The transitional character of the sandstones is well shown in a mound about 4 miles northwest of Holliday. The top of the mound, which covers about an acre, consists of soft gray sandstone resting upon red concretionary clays. On the north side the sandstone is about 10 feet thick and 25 feet of clay lies below it. On the south nearly the whole side of the hill is composed of sandstone in place, only about 5 feet of the clay being exposed.

Limestones representing higher horizons make their appearance in the bluffs of the Wichita about 5 miles north of Dundee station, on the west side of Horseshoe Lake, where the section following is exposed:

Section in bluff on west side of Horseshoe Lake, Wichita County, Tex.

	Feet.
1. Limestone, hard, dark blue, brown on exposure, cavernous	4
2. Blue clay	4
3. Red concretionary clays	25
4. Soft red shaly sandstone	15
5. Red concretionary clay	4
6. Red shaly sandstone	9
7. White and red variegated sandstone, more massive than Nos. 4 and 6	6
8. Nodular clay ("conglomerate")	1
9. Red concretionary clay	15
10. Nodular clay or "conglomerate"	⅓
11. Red concretionary clay	25
	108⅓

Scattered over the upland surface in the vicinity of Electra are fragments of limestone that were weathered out of the clays, but no limestones were seen in place in the northern part of the county. About three-fourths of a mile southwest of Electra some thin nodular limestones are exposed, interbedded with blue nodular clays, calcareous shales, and sandstones.

Recent deposits are represented in the main valleys by considerable thicknesses of alluvial sands and gravels. In the valley of the Wichita these deposits are from 20 to 30 feet thick. Their thickness in the valley of Red River is not known. Traces of the presence of similar but older deposits appear in the upland areas in the form of rounded pebbles of quartz and other crystalline rocks scattered over the surface. In places small patches of these gravels have been consolidated into a conglomerate a few feet thick. They are possibly of Tertiary or early Pleistocene age.

A prospect well for oil was put down at Electra some years ago by W. T. Waggoner, but no authorized record of this well can be obtained. The hole is located near the railroad station, which has an elevation of 1,229 feet above sea level. The driller was B. P. Gates. Information concerning this well was supplied by Mr. Estes, who assisted in the sinking of the well. He states that the drilling was extended to a depth of 1,790 feet, passing through the following strata:

Record of the Waggoner oil well, Electra, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
1. Surficial material	8–10	10
2. Red concretionary clay	50	60
3. Red joint clay	45	105
4. Red variegated clays and shales, sandy shales alternating with blue	645	750
5. Sand with some oil; water struck at bottom of sand rose within 15 feet of the surface	50	800
6. Shale, alternating with other rock; blue shale at 1,200 feet	990	1,790

Water was first reached in quantity at 800 feet. Above this there was only a slow seepage. The water at the 800-foot horizon is salty and mingled with a small amount of oil, which stands at the surface and is dipped out for use locally by cattlemen.

Since 1907 borings in the vicinity of Electra have revealed the presence of extensive deposits of oil in that region. As stated elsewhere (p. 47), the principal oil area is in the western part of Wichita County, in the vicinity of Electra. The region as a whole now produces about 10,000 barrels of oil a day, the larger part of which is derived from the Electra field. There are several oil-bearing sands, of which the one most explored lies 900 to 1,000 feet below the surface, in the lower part of the Wichita formation. Below this are others with which have been correlated some that occur in the Henrietta-Petrolia field.

WATER CONDITIONS.

WELLS.

In the alluvial flats along Wichita and Red rivers plentiful water supplies are found at depths of 20 to 25 feet.

In the valley of the Wichita supplies are obtained generally from wells varying from 18 to 25 feet in depth. At the Tom Jones ranch, northwest of Holliday station, an abundant supply of very good water is obtained from a well 22 feet deep. The section is as follows:

Section of well on Tom Jones ranch, near Holliday, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and sandy clay	8	8
Gravel	4	12
Sandy clay	6	18
Sand with a plentiful supply of good water	4	22

In the upland areas few good wells are found. The water in these wells is derived from the red shales and sandstones of the Wichita formation and is usually too highly mineralized for use. Some of the shallow wells yield supplies for stock, but few of them are available for domestic use. The depth of these wells is from 16 to 50 feet, the principal supplies being obtained at about 45 feet. The water from these shallow upland wells is rich in salt and gypsum, as is shown in analysis No. 2 of the subjoined table. The water from the deeper horizons shows a much greater content of mineral matter, as indicated by analysis No. 3. This water is absolutely unfit for domestic or industrial use or for irrigation.

The character of the water from the wells at Wichita Falls is shown in the following analyses:

Analyses of well waters from Wichita Falls, Tex.

[Parts per million.]

	1	2	3	4
Silica (SiO_2)	9.6	12	7	117
Iron (Fe)	Tr.	.05	.05	6.4
Aluminum (Al)	.....	.....	4	34
Calcium (Ca)	28	187	1,397	18
Magnesium (Mg)	42	86	411	15
Sodium (Na)	252	739	16,611	14
Potassium (K)			43	
Carbonate radicle (CO_3)	19	.0	.0	.0
Bicarbonate radicle (HCO_3)	395	289	93	60
Sulphate radicle (SO_4)	292	294	512	20
Chlorine (Cl)	102	1,380	29,077	22
Nitrate radicle (NO_3)	Tr.	33	.02	.88
Suspended matter	2.8	.....	.....	120
Total dissolved solids	927	2,953	48,726	310
Turbidity	5	.....	.....	165

1. Elevator well in alluvial deposits. Depth, 20 feet. W. M. Barr, analyst. Sample collected Oct. 1, 1906.
2. Edson A. Chamberlin's well, Bluff Street. In red shales and sandstone of Wichita formation. Depth, 40 feet. Walton Van Winkle, analyst. Sample collected in 1906.
3. Well owned by F. D. Keona (?). Depth, 220 feet. J. B. Bailey, analyst. Sample collected June 8, 1911.
4. City water from artificial lake. W. M. Barr, analyst. Sample collected Oct. 1, 1906.

According to R. B. Dole, of the United States Geological Survey, the water of the Keona well will yield on evaporation a residue containing 86 to 88 per cent of sodium chloride (common salt), the chief impurities of which would be calcium chloride and calcium sulphate. He considers it worth investigating as a possible local source of salt. The percentage composition of the anhydrous residue computed from the analysis is as follows:

Percentage composition of anhydrous residue from water of Keona well, Wichita Falls, Tex.

Chlorine (Cl)	60.5
Sodium (Na)	34.5
Calcium (Ca)	2.9
Magnesium (Mg)	.8
Sulphate radicle (SO_4)	1.1
Potassium (K)	.1
Carbonate radicle (CO_3)	.1
	100.0

In the upland areas cisterns and tanks constitute the chief source of water supply for domestic use and for stock. The water thus stored holds in suspension a large amount of red sediment derived from the adjacent soils. This matter settles very slowly, and the rivers and ponds are rarely clear. The city of Wichita Falls is supplied from a reservoir 7 miles long. The character of the water, as shown by a sample taken from the pipes before filtering, is indicated by analysis No. 4. The water is red-brown in color and is not clear after filtering. The high content of silica, aluminum, and iron is due to the ferruginous clay held in suspension.

SPRINGS.

There are a few springs in the county along the sides of the valleys of the main streams or their tributaries. Most of them are the result of the deepening by erosion of the valley to the level of the water table in the alluvial deposits. One of these springs is located about 4 miles northwest of Electra, in the valley of a small tributary of Red River. The water issues from the west bank of the stream for a distance of 100 yards. The main spring is about 25 yards back from the stream. It yields a considerable flow of slightly brackish water.

ARCHER COUNTY.

PHYSIOGRAPHY.

Archer County has an area of 960 square miles. The population according to the census of 1910 was 6,525; the county seat is Archer City. The county lies at an altitude of 1,000 to 1,200 feet. The mean annual rainfall is 30 inches.

The northern and southern portions of the county consist of extended rolling plains. The middle portion of the county is dissected by Little Wichita River, which flows from west to east directly across the county.

GEOLOGY.

With the possible exception of a small area in the extreme southeast corner of the county the rocks appearing at the surface belong to the Wichita formation of the Permian series. They consist for the most part of the red shales and sandstones characteristic of the formation in this part of the State. Near the western boundary thin beds of limestone appear at wide intervals, alternating with blue and red clays and sandstones. These strata constitute the lower portion of a series of limestones which belong to the upper part of the formation. The bones of vertebrates and the remains of plants that have been collected at different places in the middle and western parts of the county have contributed to the determination of the Permian age of the Wichita formation.

Deposits of copper have been found in the county, and at one time development was attempted, but the results were not satisfactory. The ore occurs in the form of nuggets and masses (some due to replacement of wood) distributed in beds of blue clay which are themselves highly impregnated with copper.[1]

WATER CONDITIONS.

There are very few wells in this county. Water supplies are drawn chiefly from cisterns and artificial ponds or "tanks." D. M. Segler, a well driller, states that he has drilled many wells in this region and

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 449–455. Schmitz, E. J., Copper ores in Permian of Texas: Trans. Am. Inst. Min. Eng., vol. 26, 1896, pp. 97–108.

has found but one good well in the northern part of Archer County. The water from shallow wells is in general strongly mineralized, but some wells yield water that can be used. These wells are from 16 to 30 feet deep. At depths between 60 and 600 feet from the surface are found four or five beds which contain an abundance of water, but it is invariably salty and unfit for use. The water from these beds rises on being struck by the drill, but usually fails to reach the surface.

In 1906 three wells were put down in the vicinity of Geraldine by the Geraldine Coal & Oil Co. in the search for oil, of which only traces were found. The record of one of these wells was furnished by the driller, Mr. F. D. Kerns:

Record of well No. 3 at Geraldine, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil, followed by red joint clay	90	90
Gray sandstone, water in lower part	16	106
Red clay	2	108
Brown clay	20	128
Red clay	15	143
Brown clay	55	198
Gray clay and fine sand	30	228
Red clay	24	252
Yellow clay	28	280
Gray sandstone with salt water which came within 20 feet of the top of the well	18	298
Red clay	22	320
Blue soapstone	18	338
Red shale with water at top	8	346
Quicksand with a thin seam of coal; water in the quicksand	4	350
Soapstone	2	352
Red shale; showing of oil and gas	178	530
Soft blue sandstone, water at top; water salty and flows out at top	10	540
Fine white sand	30	570
Red shale	2	572

At Archer City several attempts were made to find potable water in the deeper beds. The courthouse well is said to be 480 feet deep, and salty water was found in it at 125 and 180 feet. The following is the record of a well put down at Archer City, according to F. E. Roesler:[1]

Record of well at Archer City, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	25	25
Sandrock	10	35
Red clay and hardpan	500	535
Black soil	5	540
Light-red clays	30	570
Cap rock	½	570½
Red clay	100	670½
White rock	10½	681
Sandrock	14	695
Soft white rock	7	702
Red clay	5	707
Sandrock	6	713
Soapstone	11	724
Gravel with water	1	725
Sandrock (water)	12	737

[1] S. Ex. Doc. No. 222, 51st Cong., 1st sess., 1890, p. 262.

The water found in the gravel and sandrock at the bottom rose but did not flow out at the top. Elsewhere in the same report[1] mention is made of salt water occurring at 500 feet.

No wells have been put down in the vicinity of Holliday, water being obtained from ponds and cisterns.

At Dundee also cisterns and ponds constitute the source of supply both for domestic use and for stock. There are no wells in the town and very few in the surrounding country. Small supplies are found at depths of 18 to 24 feet.

At Windthorst wells range in depth from 16 to 170 feet. The most common depth is 40 feet, but the largest supplies are found at a depth of 65 feet. In the shallow wells the water is mostly soft, and in the deeper wells it is alkaline. In this vicinity wells and cisterns are relied on for water for domestic use and ponds for stock.

At Geraldine water is found in shallow wells at depths of 20 to 40 feet, but cisterns and ponds are the most satisfactory source for all uses. In the borings made for oil (p. 56) water was found at 90–106, 280–298, 338, and 530 feet. The water from the lowest bed flowed 6½ feet above the surface and would probably rise higher. In all the borings the water was strongly salty.

WILBARGER COUNTY.

PHYSIOGRAPHY.

Wilbarger County includes the area between Baylor County and Red River and is bounded on the east by Wichita County and on the west by Hardeman and Foard counties. It has an area of 932 square miles and a population of about 12,000 (census of 1910); the county seat is Vernon. The mean annual rainfall is 28 inches.

The relief of the county is that of an eastward-sloping plain, or high rolling prairie, intersected by the wide, flat valleys of Pease River and Beaver Creek and their tributaries. The northern half of the county is drained chiefly by Pease River, which flows northeastward across the county into Red River. Beaver Creek drains the southern part of the county; it has a general eastward course and empties into Wichita River in Wichita County. From Electra, in Wichita County, to Harrold, in Wilbarger County, the Fort Worth & Denver City Railway runs along the crest of the divide between Beaver Creek and Red River. The elevation at Harrold is 1,235 feet above sea level. Vernon is situated on the south side of the Pease River valley, and the elevation at the St. Louis & San Francisco Railroad station is 1,205 feet. A prominent physiographic feature of the northern part of the county is a high sand ridge which runs northeastward about 6 miles north of Pease River. This ridge is several miles wide and rises about 100 feet

[1] S. Ex. Doc. No. 222, 51st Cong., 1st sess., 1890, p. 298.

above the surrounding prairie, which is estimated to be from 100 to 120 feet above the level of Pease River at Vernon. Pease River flows in a rather wide valley, following closely the northern bank and in places cutting into it. The valley plain on the south side of the river is about 1½ miles wide and is bordered on the south by terraced slopes. Within this valley the river flows in a channel about one-fourth of a mile wide. The water of Pease River fails entirely during times of extreme drought, and the same is true of Red River above the North Fork. The water of both streams, more especially of Pease River, is saline, because of the salt received from the beds through which it passes near its source. The great cattle trail leading from central Texas to Dodge City, Kans., passed through the present site of Vernon and crossed Red River at Doans. In 1885, according to J. E. Lapham,[1] there were driven through Vernon 300,000 head of cattle, 200,000 head of sheep, and 190,000 head of horses. The same writer says:

> The climate of the Vernon area is comparatively dry and is characterized by high winds and light annual rainfall. The temperature during the summer months is generally pretty uniform, averaging about 80° for the months of June, July, and August with a few sudden changes. In the fall and winter months, however, considerable fluctuation is noticed. Cold winds of great severity sweep down from the north without warning, changing the temperature through many degrees in the space of a few hours and causing at times much suffering to men and animals exposed to their force. During the months of July and August the winds sometimes carry with them the other extremes of temperature, the hot blasts at times resulting, in the course of a few hours or a day, in the total destruction of a crop of corn, wheat, or cotton.

GEOLOGY.

The rocks constituting the substructure of the county belong to the Wichita, Clear Fork, and Double Mountain formations of the Permian series. The southeastern part of the county is underlain by rocks of the Wichita, consisting of red clays and red sandstones interstratified at certain horizons with white and gray earthy magnesian limestones. These limestones represent the northern extension of the strata exposed in the bluffs of the Wichita north of Seymour. The most northerly exposures of these limestones occur on Beaver Creek 9 miles southwest of Electra. The diminution in the proportion of limestones in the formation and the change in the character of the beds themselves toward the north, as noted elsewhere (p. 23), is readily seen by comparing these exposures with those on the Wichita and at Seymour.

The western half of the county is underlain by sandstones, red clays, and conglomerates belonging to the Clear Fork formation. Limestones are few and mostly of earthy magnesian type. Irregular conglomerate beds constitute a noticeable feature of the formation. These beds appear to be composed of a mixture of clay and limestone

[1] Soil survey of the Vernon area: Field Operations Bur. Soils for 1902, U. S. Dept. Agr., pp. 365–381.

constituents, the proportion of lime carbonate being sufficient to give decided effervescence with acid.

The Quaternary deposits are represented by patches of the Seymour formation (Pleistocene) which cover the higher areas between the streams and the alluvial deposits in the valleys. The sands and gravels of this formation are from 30 to 40 feet thick in the western part of the county but thin out almost entirely in the eastern part. A line drawn from the northeast corner of Wilbarger County southwestward through Seymour will mark approximately the eastern limit of the Seymour formation. East of this line the formation seems to be represented only by small isolated patches of coarse conglomerates. The streams have cut entirely through the formation in that part of Wilbarger County in which it is found, and it appears therefore only as finger-like extensions in the interstream areas.

The bottoms of the main valleys, such as those of Pease and Red rivers, are covered to a considerable depth by alluvium, the product of the rivers themselves, and along the bluffs in the lower part of the Pease River valley and in adjacent parts of the valley of Red River is a deposit of sandy loam which may be of eolian origin and considerably older than the alluvium. Underneath this sandy loam at Red Bluff and near Doans Crossing is a bed of volcanic ash.[1]

WATER CONDITIONS.

In the valleys of Red and Pease rivers water is obtained in wells from 12 to 60 feet deep. In the Red River valley the most common depth is 12 to 20 feet. In the sandy areas adjoining the main valleys the depth is somewhat greater. The water in these wells is somewhat gypseous but as a rule is fairly good. The springs found in some places along the borders of the valleys have their origin in the old alluvial deposits now found as terrace remnants along the sides of the valleys or at the base of the Seymour formation. A notable spring of this character occurs at Doans. The flow here comes from a cluster of springs which yield a small stream that persists throughout the year. It does not reach the river on the surface, but sinks into the sands about a mile from its source.[1] Another notable spring is Condon's Spring, situated 2 miles west of Vernon at the south side of the Pease River valley. The flow here comes from several springs which issue from the base of the Seymour formation. The water is good, and a good flow is maintained throughout the year.

In the upland areas north of Pease River and south to the breaks of Beaver Creek water can be obtained in wells usually at depths of 20 to 30 feet, except where the Seymour formation has been removed by erosion. The eastern boundary of the Seymour formation is about 5 or 6 miles east of Vernon, and beyond this boundary good supplies of water in shallow wells seem not to be common.

[1] Lapham, J. E., op. cit., p. 369. [1] Idem, p. 370.

HARDEMAN AND FOARD COUNTIES.

PHYSIOGRAPHY.

The area of Hardeman County is 532 square miles and that of Foard County is 636 square miles. The population of Hardeman County is 11,213; that of Foard County 5,726. The mean annual rainfall for the two counties is about 25 inches.

The relief of the area resembles that of Wilbarger County in its essential features, comprising a high rolling eastward-sloping plain dissected by a number of eastward-flowing tributaries of Red and Wichita rivers. The elevation of the plain surface at Quanah is 1,568 feet above sea level and at Acme, 5 miles west, it is 1,578 feet, according to railroad profiles. The northern part of Hardeman County is drained by the tributaries of Red River and the southern part by Pease River, which constitutes in part the boundary between Hardeman and Foard counties. The North Fork of Wichita River drains the western part of Foard County; the eastern part is drained by the upper tributaries of Beaver Creek. In general the streams have wide valleys, but considerable tracts of level land make up the interstream areas.

GEOLOGY.

These counties are underlain by rocks belonging to the Clear Fork and Double Mountain formations of the Permian series. Over considerable areas these beds are covered by later formations, but exposures are numerous along the sides of the valleys and in the ravines tributary to them. In the eastern part of the counties the rocks consist of red clays, red sandy shales, and red sandstones, with a little gypsum in thin scattered seams. The slight westward dip of the strata, combined with the eastward slope of the surface, brings later beds to view in the western part of the counties, where the rocks consist of red clays and sandstones alternating with blue clays and sandstones, beds of gypsum, and some limestones. The gypsum occurs in lenses from a few inches to 8 or 10 feet thick. The lack of persistency in the gypsum beds and their associated magnesian limestones and the varying position of the beds vertically render ineffectual any attempt to correlate the different deposits except within small areas. A composite section taken between Crowell and Quanah shows the following formations:

Section showing rocks exposed between Crowell and Quanah, Tex.

Soil, dark; thins out on approaching breaks of Pease River.	Feet.
Limestone	5
Blue clay	15
Gypsum	3
Red and blue clays, with thin layers of limestone	10
Gypsum	2
Blue clays	15
Gypsum	2

A. OUTCROP OF GYPSUM AT ACME, TEX.

B. SPRING FROM THE CANYON FORMATION AT JACKSBORO, TEX.

	Feet.
Red and blue clays, with some thin beds of red sandstones	20
Red sandstones, cross-bedded	4
Red clays, with thin beds of sandstone	10
Bluish-white sandstones, cross-bedded	5
Red clays, with seams of gypsum	15

The uplands south of Pease River in the vicinity of Crowell and south to the breaks of North Fork of Wichita River are covered by fine black silt 6 to 8 feet thick underlain by gravel (Seymour) 2 to 3 feet thick. The gravels rest upon red joint clay of the Permian. A well drilled in the southeastern part of Quanah by J. J. Cyrus gave the following section:

Section of well at Quanah, Tex.

[Elevation, 1,570 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
1. Black dirt	5	5
2. Red clay	5	10
3. Blue clay	5	15
4. Limestone	5	20
5. Red and blue clay	20	40
6. Gypsum and clay	25	65
7. Red and blue clay	10	75
8. Gypsum, replaced locally by limestone	8	83
9. Thin bed of gravel with water	2±	85±
10. Light-colored clay	10±	95±

In the center of town bed No. 6 is all clay and No. 8 is replaced by limestone.

Gypsum is quarried at Acme (Pl. II, *A*), 5 miles west of Quanah, and also at Gypsum, 10 miles west.

The Seymour formation appears in the interstream areas in thin beds of gravel resting upon the eroded surface of the Permian red clays. These clays when struck in wells are called "Birdseye" by the drillers, from their variegated appearance. In Foard County the Seymour formation is about 10 to 15 feet thick and consists of gravel below and a dark silt above. This formation was apparently deposited in a small body of fresh water, which long ago vanished.

The wide bottoms of the streams are covered by alluvial deposits of considerable depth. The rivers are constantly at work upon these deposits and change their channels from time to time, making the maintenance of bridges expensive and troublesome. Hence bridges are few and the streams are usually crossed by fording.

WATER CONDITIONS.

In Hardeman County the Seymour formation is thin or absent, and supplies of well water are found in the Permian rocks at depths of 40 to 150 feet. The water obtained in these wells differs greatly in quality, but in general it is highly mineralized. For the most part cisterns are relied upon for domestic supplies.

At Quanah water is found in the center of town in a porous limestone (No. 8, p. 61) at a depth of 75 feet. Locally this limestone is replaced by gypsum and the water occurs in a thin stratum of gravel below the gypsum bed. The city supply is drawn from this zone. The limestone is not uniformly porous and considerable differences exist in wells put down to this horizon. The water found in limestone is of fairly good quality, but that in other rocks is gypseous.

At Acme wells and creeks supply water for general purposes. Most of the water for drinking is shipped in, and the supply for other domestic uses is obtained from cisterns. The wells are from 60 to 160 feet deep, the most common depth being 100 feet. Acme is situated on South Grosbeck Creek, a perennial stream supplied from springs.

In Foard County water for domestic use is derived mostly from shallow wells and cisterns. Over a considerable part of the county water is found in the Seymour formation at depths of 10 to 20 feet. Elsewhere the Seymour formation is thin or altogether absent, its water supply is small, and in places it is dry. Springs which derive their supply from it occur in many places along the sides of valleys where the streams have cut through the formation. Some wells extend into the Permian clay below. The water from these wells is usually too highly mineralized for general use. Some of the water from the gravels of the Seymour formation is fair, but as a rule it is more or less mineralized.

At Margaret water for domestic use is obtained from wells about 20 feet deep. Artificial ponds furnish water for stock.

In the vicinity of Thalia both wells and cisterns are used for domestic supplies, the water being found at depths of 12 to 50 feet.

At Crowell most of the water used is obtained in the gravel underlying the black soil at 12 to 20 feet. This supply is inadequate, however, and is supplemented by cisterns and tanks.

Analyses of water from wells at Quanah are given below:

Analyses of water from wells at Quanah, Tex.

[Parts per million. Analyst, B. L. Glascock.]

	1	2
Silica (SiO_2)	16	18
Iron (Fe)	.6	1.2
Aluminum (Al)	2.2	1.0
Calcium (Ca)	406	252
Magnesium (Mg)	79	85
Sodium (Na)	46	74
Potassium (K)	13	12
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	249	151
Sulphate radicle (SO_4)	1,141	816
Nitrate radicle (NO_3)	5.0	19
Chlorine (Cl)	60	173
Total solids	1,988	1,618
Turbidity	0	0
Date of collection	Sept. 12, 1907	Sept. 24, 1907

1. Well of Bert Abbott. Depth, 65 feet. Upper Permian.
2. Well at ice plant. Upper Permian.

The following note has been prepared by R. B. Dole:

Both waters are too high in mineral content, and especially in sulphates, to be very good for domestic use, though they are drinkable. They would be corrosive and contain too great quantities of scale-forming ingredients to be suitable for boiler use. The chemicals necessary to correct the scaling and corroding tendencies would render them likely to foam badly in boilers.

KNOX COUNTY.

PHYSIOGRAPHY.

Knox County, which adjoins Foard County on the south, is rectangular in outline and contains an area of 947 square miles. Its population is 9,625. The county seat is Benjamin. The mean annual rainfall is 25 inches.

The surface consists of a rolling eastward-sloping plain intersected by the wide valleys of the Salt Fork of Brazos River and the North and South forks of Wichita River. Considerable areas between the drainage systems remain undissected. The soil in these upland areas is generally of excellent quality and well suited to agriculture. The bottom lands, where not subject to overflow, offer favorable conditions for farming, but at the sides of the valleys there are considerable areas of badlands due to the erosion of the Permian shales and sandstones. The present valley of the Salt Fork has a depth of about 75 feet below the general plain level, which ranges from 1,475 to 1,525 feet above the sea. The valleys of Wichita and Brazos rivers are 3 to 4 miles wide, the main valley plains having a depth of about 50 feet below the general surface. Within these older valleys and about 10 feet below their level the rivers have cut later valleys with terraced slopes. The rivers flow in channels about 10 feet deep in the bottoms of these later valleys.

GEOLOGY.

The substructure of Knox County consists entirely of the red clays and sandstones, with their associated blue shales and gypsum, belonging to the Clear Fork and Double Mountain formations of the Permian series. These formations outcrop extensively along the valleys of the streams, but in the upland areas they are covered by the sands and gravels of the Seymour formation. A section taken in the breaks of the South Fork of the Wichita near the road leading north from Benjamin shows the following formations:

Section in breaks of the South Fork of Wichita River.

	Feet.
Pleistocene:	
Sand and gravel with lenses of red clay. Gravels contain numerous worn shells of Gryphæa (Seymour formation)	25
Permian:	
Red clay with white spots ("Birdseye" of drillers)	10
Bluish-white clay grading horizontally into magnesian limestone	1–5
Red clays mottled with white ("Birdseye" of drillers) with lenses of limestone and gypsum	15

In the southern part of the county the surface formations consist of 30 feet of the sand and red silts underlain by gravels (Seymour formation). In these are often found the bones and teeth of mammals, Mastodon and Equus, as noted elsewhere (pp. 31).

WATER CONDITIONS.

Where well developed the Seymour formation usually contains water of good quality. The supply is not everywhere abundant, however, and some wells extend through the Seymour into the Permian beds before obtaining water.

The red clays of the Permian constitute the source of supply in many wells, but the water from them is always mineralized, so much so in places that it can not be used. The wells are of varying depth, usually more than 50 feet.

The deep-water conditions are not such as to warrant the expectation of finding potable supplies of water within the range of practicable drilling.

HASKELL COUNTY.

PHYSIOGRAPHY.

The surface of Haskell County consists of a high rolling plain which rises toward the west. The county has an area of 843 square miles, and its population in 1910 was 16,249, an increase of over 500 per cent in the decade since 1900. The county seat is Haskell. The mean annual rainfall is 25 inches. There are few streams in the county, and these are small and unimportant. The eastern part of the county is drained by Paint and Millers creeks, the former flowing eastward into the Clear Fork and the latter northeastward into the Salt Fork south of Seymour. In the western part of the county the Double Mountain Fork of the Brazos swings eastward into the county, but leaves it again before reaching the northern boundary.

At Haskell the elevation at the station of the Wichita Valley Railway is 1,574 feet above sea level. At Rule, on the open plain about 10 miles west of Haskell, the elevation is 1,672 feet at the Kansas City, Mexico & Orient Railway. Carney, near the northern boundary of the county, nearly due north of Rule, on the same railway, is 1,560 feet above sea level.

GEOLOGY.

The geology of Haskell County does not differ essentially from that of Knox County. The Seymour formation has a thickness of about 30 feet over the eastern part of the county but thickens toward the west to 50 or 60 feet. For the most part the streams cut through this formation into the red beds of the Permian below. The larger part of the Seymour formation consists of fine red and yellow calcareous clay or silt containing a varying amount of sand. The red

clays, which are 20 to 30 feet thick, rest upon about 10 feet of sand and gravel. In places the calcareous clays are consolidated in their upper portion into an irregular deposit of impure limestone, the caliche of the semiarid regions (p. 32).

WATER CONDITIONS.

At Haskell water is obtained from the gravel bed at the base of the Seymour formation. The wells are generally from 20 to 35 feet deep in the vicinity of the town. As the formation thins toward the south, the wells are shallower in that direction. Where the streams have sunk their channels through the gravels, springs may appear, as, for example, the Rice spring at Haskell.

West of Haskell the wells in the gravels increase somewhat in depth, owing to the thickening of the formation. On approaching the Double Mountain Fork, whose channel extends considerably below the level of the gravels, these beds appear to be bereft of water and the wells extend some distance into the red clays (Permian) before striking water, which, as elsewhere in this series, is of poor quality.

The following table gives several analyses of Haskell County waters:

Analyses of ground waters in Haskell County, Tex.

[Parts per million. Analyst, B. L. Glascock.]

	1	2	3	4	5
Silica (SiO_2)	23	29	20	37	20
Iron (Fe)	.35	.6	1	.3	.2
Aluminum (Al)	5.6	.4	3.8	.8	.4
Calcium (Ca)	464	30	311	70	259
Magnesium (Mg)	301	16	120	30	106
Sodium (Na)	2,377	133	190	72	195
Potassium (K)	25	6.5	8	8	25
Carbonate radicle (CO_3)	19	19	4.8	2.4	0
Bicarbonate radicle (HCO_3)	571	283	202	373	150
Sulphate radicle (SO_4)	3,512	134	1,237	50	1,148
Nitrate radicle (NO_3)	1.06	26	4	11	2.5
Chlorine (Cl)	2,512	102	169	21	174
Total solids	9,469	626	2,320	446	2,065
Turbidity	0	0	0	0	0
Date of collection	Sept. 6, 1907	Sept. 6, 1907	Sept. 24, 1907	Sept. 24, 1907	Sept. 12, 1907

1. Well of J. W. Westbrook, at Haskell, Tex.; depth, 10 feet. Seymour formation.
2. Courthouse well at Haskell, Tex.; depth, 20 feet. Seymour formation.
3. Well "Harder water," at Rule, Tex.; depth, 75+ feet. Upper Permian.
4. Well, "Softer water," at Rule, Tex.; depth, 40–50 feet. Seymour formation.
5. Foster & Jones's hotel well at Rule, Tex.; depth, 60 feet. Seymour formation.

The following note regarding the usefulness of these waters has been prepared by R. B. Dole, of the United States Geological Survey:

The first water is so strong that it is unfit for use. Analyses 2 and 4, of calcium-carbonate waters only moderately mineralized, represent the best supplies. These two waters are fairly well adapted to irrigation and to use as boiler feed and are acceptable for domestic service. The waters represented by analyses 3 and 5 are similar to each other, being sulphate waters of too high mineral content to be very acceptable ford omestic use, though they are drinkable and may be classed as fair for irrigation; they are unfit for supplying steam boilers.

At Rule the well of Werner Rule, located in the southwestern part of the town, gives the following record, according to the driller, E. F. Heller:

Record of Rule well, at Rule, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft dark sandy soil	3	3
Hard white marl	24	27
Soft white sand and gravel	14	41
Hard reddish rock	2	43
Hard white clay	2	45
Hard red clay, water bearing	2	47
Hard red clay	17	64
Hard white clay, water bearing, yielding one-half gallon a minute	2	66

The well of Mr. Williams, located on the north side of the town, is 105 feet deep, with the following record:

Record of Williams well, at Rule, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft dark soil	3	3
Hard gray marl	27	30
Soft red sand and gravel	10	40
Hard reddish rock	2	42
Hard gray clay	1	43
Hard red clay, water bearing	12	55
Hard white clay, water bearing	2	57
Hard red clay	28	85
Hard grayish clay, water bearing	2	87
Hard red clay	8	95
Hard grayish clay, water bearing	5	100
Hard red clay	5	105

Ten miles northwest of Rule, on the farm of W. E. Pyeatt, is a well whose record, according to the driller, E. F. Heller, is as follows:

Record of Pyeatt well, near Rule, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft dark sandy soil	5	5
Hard red sand	15	20
Hard gray marl	5	25
Soft red sand	52	72
Hard red clay	5	82
Hard white clay, water bearing	1	83
Hard red clay	24	107
Hard red clay, water bearing	1	108
Hard red clay	4	112

About 12 miles southwest of Rule, on the farm of C. Boardner, is a well 70 feet deep, with the following record, according to the same authority:

Record of Boardner well, near Rule, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Black firm soil	3	3
Hard chalky soil	9	12
Reddish soft sand	4	16
Hard red stone	3	19
White soft sand	2	21
Hard red clay	31	52
Hard grayish clay, water bearing	1	53
Hard white sandstone	16	69
Soft blue clay, water bearing		70

The water in the Boardner well is said to rise within 40 feet of the surface.

Many wells in the western part of Haskell County derive their supplies from the Seymour formation at depths of 40 to 50 feet. The water from this horizon is reported as "soft" and fairly good. The water in the deeper wells is obtained from the Permian beds and is more highly mineralized.

BAYLOR COUNTY.

PHYSIOGRAPHY.

Baylor County has an area of 957 square miles and in 1910 had a population of 8,411. The mean annual rainfall of the county is 38 inches. The altitude of the county is approximately 1,500 feet above sea level. The north half of the county is drained by Wichita River, formed by the junction of the South and North forks in the western part of the county. The Salt Fork of Brazos River flows in a southeasterly direction across the southern part of the county. For the most part these streams flow in rather wide valleys. At Seymour the Salt Fork cuts across a belt of limestone, and in this part of its course its valley is narrower.

The surface of the county in the interstream area is a high rolling plain. In the valley of the main stream and over portions of the uplands the soil is fertile and capable of producing abundant crops.

GEOLOGY.

The indurated rocks of the county belong to the Permian series. The Wichita formation crops out over the eastern half of the county, and in this area some of the most interesting Permian fossils have been found. The rocks, which consist of blue and red shales and white to bluish-gray magnesian limestones, constitute the upper portion

of the Wichita formation. At Seymour, where the river has cut into the formation, the following section was obtained:

Section at Seymour, Tex.

	Ft.	in.
Light-reddish sandy soil at surface, underlain by dark-red sandy soil	20 to 25	
Blue shale, with thin ledges of magnesian limestone	6	
Limestone in massive beds, passing horizontally into shaly beds	5	
Dark clay shale	1	6
Concretionary calcareous shale and limestones		6
Limestone in two massive ledges separated by 1 to 4 inches of blue clay shale	3	
Blue shale	10	
Argillaceous limestone and dark-blue shale	3	
Limestone with varying proportions of shale	4	
Blue clay	3	
Red clay	5	
Blue clay	2	
Limestone	2	
Blue clay shale	5	
Limestone		6
Blue clay shale	4	
Limestone	1	6
Blue shale, with lenses of limestone	3	
Blue clay shale, interbedded with thin limestone	2	
Limestone	16	
	102	

These limestones outcrop in a belt extending southward from this point across Throckmorton County and beyond. North of Seymour they were observed in the valley of Wichita River, east of the Seymour-Vernon road, and also on Beaver Creek. In their northward extent the limestones diminish in thickness, and there is a corresponding increase in the proportion of red clays and shales. Many of the limestones are white and chalky and in beds of this kind near Mabelle abundant fragments of vertebrate remains were seen, among them being the piece of a jaw of a vertebrate, but vigorous search failed to bring to light remains sufficient for identification. Williston[1] has recorded the discovery in 1909 in Baylor County of the remains of vertebrates, among which are several forms new to science. Some of these were found about 6 miles east of Seymour and others on West Coffee Creek.

The Seymour formation constitutes the formation at the surface over the upland areas west of the town of Seymour, which lies upon the sand of this formation. The formation does not occur generally east of Seymour, but in some places, as near Mabelle station, there are patches of conglomerate which possibly represent outliers of the formation.

[1] Jour. Geology, vol. 17, 1909, pp. 636–658; vol. 18, 1910, pp. 526–536, 585–600; vol. 19, 1911, pp. 232–237.

WATER CONDITIONS.

In the eastern part of the county cisterns are in common use for supplies of water for domestic purposes, but tanks are the chief resource for stock. Some wells are used in the upland areas, where, however, the water is not generally of satisfactory quality. In the western part of the county fairly good water is found in the Seymour formation, and in the sands and gravels along the main valley. The depth of the wells in this area is from 15 to 45 feet, the most common depth being 20 to 25 feet. Some wells extend below the Seymour formation into the underlying formation, but these invariably yield gypseous water.

The character of the water obtained from the Seymour formation at Seymour is shown by the following analysis of the water from the roundhouse well:

Analysis of water from roundhouse well, Seymour, Tex.

[Parts per million. W. M. Barr, analyst. Sample collected Nov. 1, 1906.]

Silica (SiO_2)	22
Iron (Fe)	.05
Calcium (Ca)	61
Magnesium (Mg)	32
Sodium (Na) and potassium (K)	183
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	401
Sulphate radicle (SO_4)	86
Chlorine (Cl)	152
Nitrate radicle (NO_3)	9.7
Total solids	746
Suspended matter	0

Along the valley of Salt Fork water is found in the sands and gravels at depths of 15 to 25 feet. In some places the water is of good quality, but generally it contains a considerable amount of mineral matter.

The following are analyses of water from two wells at Round Timber:

Analyses of water from wells at Round Timber, Tex.

[Parts per million. Samples collected Oct. 9, 1906.]

	Gin well; depth about 20 feet.	Well 200 yards northeast of the store; depth 40 feet.
Silica (SiO_2)	24	28
Iron (Fe)	.6	.4
Calcium (Ca)	139	82
Magnesium (Mg)	51	54
Sodium (Na) and potassium (K)	79	323
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	437	414
Sulphate radicle (SO_4)	172	173
Chlorine (Cl)	130	401
Nitrate radicle (NO_3)	4.3	40
Total solids	839	1,318
Turbidity	0	5

The differences in the analyses of these waters are probably due to the fact that the well at the store derives its supply in part from the Wichita formation. The character of the water, considered in connection with the depth and location of this well near the side of the valley, indicates that the bottom of the well is in the shales of the Wichita formation.

At Shady, in the southwestern part of the county, water is obtained chiefly from open wells, ranging from 15 to 40 feet in depth, the most common depth being 35 feet. These wells have their source of supply in the Seymour formation. The well of J. F. Jones is 93½ feet in depth, and evidently finds water in the Permian clays underlying the Seymour formation.

Springs are rare in the county. They exist chiefly where streams have cut their channels to the level of the ground water in the Seymour formation. The most notable spring in this region is owned by Albert Par, of Shady.

THROCKMORTON COUNTY.

PHYSIOGRAPHY.

Throckmorton County lies south of Baylor County and east of Haskell. It has an area of 821 square miles and a population, according to the census of 1910, of 4,563; its county seat is Throckmorton, situated near the center of the county. The mean annual rainfall is 28 inches.

The surface is high and rolling and there are few streams of importance. The Clear Fork of the Brazos cuts off a small triangular area in the southwest corner and the Salt Fork a like area in the northeast corner of the county. The county is drained by these two streams and their tributaries. The interstream areas, which are either flat or gently rolling, constitute remnants of an extensive plain into which the tributaries have cut wide and shallow valleys. The topography is characterized by a benchlike structure resulting from the resistance offered to erosion by a series of heavy beds of limestone. The eastward-facing scarps of these limestones constitute a series of rock terraces that extend in a north-northeastward direction through the middle of the county. These terraces have their best development, however, farther south in Shackelford and Stephens counties.

GEOLOGY.

Except in small areas in the northwestern part of the county and along the eastern boundary the rocks outcropping in Throckmorton County belong to the Wichita formation. The beds strike nearly north and south and dip slightly to the west. The upper part of the formation is made up of heavy beds of hard limestone alternating with thicker beds of blue and red shales and sandstones. The limestones

appear about 8 miles east of Throckmorton and cap the higher levels throughout the middle and western portions of the county. These beds outcrop in prominent escarpments on the north side of the Clear Fork and farther north wherever the streams have eroded their channels through them.

The limestones vary in color from grayish white to blue and in texture from earthy and granular to hard and compact. Some of the layers are thick and massive, and although the limestones constitute the minor part of the formation, their resistance to erosion makes them, in the area of their outcrop, the dominant features of the landscape. The character of some of these exposures will be seen from the following section of the bluff facing the Clear Fork:

Section of Wichita formation on north side of Clear Fork.

	Feet.
Soil, from a few inches to a few feet in thickness.	
Blue shales and thin beds of limestones	30
Hard earthy limestone	1
Blue shale	2
Fossiliferous limestone, earthy and containing more or less gypsum. Upper 4 feet hard, blue, and full of remains of brachiopods and gastropods, mostly changed to gypsum or calcite	10
Blue and red shales, some portions grading locally into sandy shales and sandstones. The upper part contains considerable gypsum; the lower has an abundance of iron concretions. Contains also thin lenses of limestone and gypsum; exposed	40

Three miles north of Throckmorton a 10-foot ledge of limestone yielded the following fossils:

Derbya cymbula.
Myalina deltoidea.
Aviculipinna peracuta.
Pleurophorus aff. calhouni.
Annelid n. g., n. sp.

The eastern part of the county is underlain by lower beds consisting mostly of sandy shales and sandstones with some limestones. Some hills in the southeastern part carved out of these formations by erosion are known locally as Fane Mountain. The section obtained here shows chiefly sandy shales and sandstones, blue clay shales, and scattered lenses of blue limestone. In some of the beds there is a profusion of *Myalina permiana*. Some buttes in the northern part of the county, on the Throckmorton-Seymour road, apparently belong to this horizon. They consist mostly of shales with a few thin beds of limestone and some sandstones. Many specimens of *Myalina permiana* are scattered over the surface. Red colors dominate over blue in the shales of this locality, but at Fane Mountain the reverse is true.

Beds of upper Permian age appear in the extreme western and northwestern parts of the county.

With the possible exception of a small area of Seymour formation in the western part of the county, the only deposits later in age than the Permian are the alluvial deposits along the valley bottoms.

The soils are exceedingly fertile in the limestone areas and only slightly less so in the more sandy areas.

WATER CONDITIONS.

Except in the valleys, the principal water supply is derived from pools and cisterns. Here and there a well on the upland areas furnishes good water.

Two wells in Throckmorton find water that is said to be soft at a depth of 50 feet. Few wells in the county reach a depth of more than 100 feet. Plenty of water may be found at different depths in the underlying rocks, but it is more or less mineralized and unfit for use. There is little prospect that good water can be obtained in the deep-seated beds. A few good springs occur in the county.

YOUNG COUNTY.

PHYSIOGRAPHY.

Young County adjoins Throckmorton County on the east. In shape it is rectangular (approximately square) and has an area of 821 square miles. Its population according to the 1910 census was 13,657. The county seat is Graham. The mean annual rainfall is 30 inches.

The surface of this county is more or less irregular and broken and may be characterized topographically as a plain in which denudation has proceeded to the extent of removing a large portion of the original surface and has developed a moderately mature system of drainage. The underlying rocks include several series of hard beds, whose resistance to erosion is expressed in a succession of escarpments extending from southwest to northeast. The heights of these escarpments vary according to the relative thickness of the hard and soft formations. The creeks and rivers have transected them in many places, leaving isolated hills and elevations, some of considerable size. The highest of these hills are locally called mountains, as the Belknap Mountains, near old Fort Belknap, and Flat Mountain, in the northeastern part of the county.

The county is drained by the Salt Fork of Brazos River and its tributaries, except a small area in the northeast corner, which is drained by small tributaries of the West Fork of Trinity River. The Salt Fork enters the county near the northwest corner, and after making a wide detour toward the south, receiving the Clear Fork from the southwest, passes out at the southeast corner. The principal tributary lying wholly within the county is Salt Creek, which, with its affluents, drains the northeastern portion of the county.

GEOLOGY.

By far the larger part of the rocks outcropping in Young County belong to the Cisco formation, but the Wichita formation occupies a narrow belt along the west side of the county. In the extreme southeast the Salt Fork has cut through the Cisco, exposing the canyon formation in the immediate vicinity of the stream.

The beds exposed in the western part of the county consist of sandy shales and sandstones, blue shales, and a few limestones, representing the lower division of the Wichita as seen in eastern Throckmorton County. The surface is covered with a mantle of residual soil which hides the indurated rocks more or less completely. Moreover a close correspondence in lithologic character exists between the lower beds of the Wichita formation and the upper beds of the Cisco, and hence the boundary line between the two formations as shown on the accompanying map is to be considered as approximate only.

The Cisco, which underlies the larger part of the county, consists chiefly of sandy shales and clays, sandstones, and conglomerates, with a few beds of limestone and two or more beds of coal. The conglomerates are made up of waterworn siliceous pebbles in a sandy matrix, with numerous concretions of iron ore, often in hollow nodules. They pass locally into pebbly sands and coarse-grained sandstones. Owing to their resistance to erosion, the conglomerates cap many of the hills and escarpments. The sandstones are mostly coarse grained and yellowish to red and white. The clays are blue, yellow, and red, or in places variegated. There is a transition in color from blue, which prevails at the south side of the county, to red, which is the predominating color at the north. The limestones are scattered through the formation, but are more characteristic of the upper part. They range in thickness from a few inches to about 2 feet. The banks of the Salt Fork expose several strata of limestone, one of which is underlain by a bed of coal. This coal appears at the bridge crossing, west of Graham, and at Millers Bend crossing several miles above. The combined section obtained in these two places is as follows:

Section between Millers Bend crossing and bridge crossing.

	Ft.	In.
Soil.		
Limestone		10
Shales, blue, some layers sandy	70	
Limestone	1	
Blue shales	2	
Limestone, fossiliferous	2	
Coal; not well exposed; thickness estimated at about 1 foot.		
Fire clay filled with brown iron ore	6	
Blue clay shales with alternating layers of red clays containing iron concretions	10	
Sandy shales and sandstones	15	
	106	10

In the vicinity of old Fort Belknap coal is mined from a seam lying above the one indicated in this section. In 1907 Williams & Merrill were taking out coal from the bed of a small stream about a mile north of Fort Belknap by stripping. The coal is exposed for some distance in the bed of the stream and at the place worked has a thickness of 3 feet. Within a distance of 25 yards upstream it thins to 20 inches of impure shaly coal. About 150 yards north of this point at Clark & Merrill's mine, the same seam is reached by a short slope. The coal here is 3 feet thick and is overlain by 20 feet of sandy shales with a thin seam of coal near the top. Above these are sandstones 30 to 40 feet thick. A detailed description of the coal formations of Young County is given by Cummins.[1]

A section of the rocks exposed in the bank of Salt Creek opposite the gin at Graham is given on page 19.

A well put down at Graham a number of years ago gave the following section:[2]

Section of well at Graham, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy loam	16	16
Blue sandy clay	3	19
Gravel and sand	8	27
Conglomerate	16	43
Cream-colored clay	8	51
Yellowish and bluish sandstone	10	61
Hard yellow sandstone	5	66
Coal	1	67
Coarse yellow soft sandstone	4	71
Hard quartzose sandstone	13	84
Fire clay, bluish	42	126
Hard brown clay	5	131
Brown sandstone, porous (gas)	5	136
Clay and slate	9	145
Brown clay, very hard	8	153
Variegated clay	148	301
Fire clay with thin stratum of shale	70	371
Black "slate" with gas	8½	379½
Red shale	10	389½
Sandstone	1½	391

The record of a prospect hole 3½ miles southwest of Belknap was kindly furnished by the owner, Judge R. F. Arnold, of Graham. This hole is located in what is known as Sugar Hollow, on Gibbon Creek. The drill began near the top of the Cisco but did not penetrate the full thickness of that formation.

[1] Cummins, W. F., Second Ann. Rept. Texas Geol. Survey, 1890, pp. 492–502. [2] Idem, p. 505.

Record of Belknap well, 3½ miles southwest of Belknap, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
1. Rock concrete (conglomerate)	3	3
2. Yellow clay	4	7
3. Carbonaceous limestone	4	11
4. Gray clay	2	13
5. Limestone	1½	14½
6. Fire clay	3½	18
7. Rock (?)	2	20
8. Spotted clay	5	25
9. Sandstone	8	33
10. Slate	3	36
11. Coal ("Belknap coal")	2½	38½
12. Soapstone	7½	46
13. Sandstone	3	49
14. Soapstone	5	54
15. Limestone	3	57
16. Blue clay	1	58
17. Carbonaceous limestone	2	60
18. Soapstone	6½	66½
19. Slate	4½	71
20. Fire clay	5	76
21. Carbonaceous limestone	2	78
22. Blue clay	1	79
23. Carbonaceous limestone	2½	81½
24. Blue clay	1½	83
25. Carbonaceous clay	5½	88½
26. Coal, "of good quality"	2½	91
27. Blue clay	10	101
28. Fire clay	6	107
29. "Mineral" clay	10	117
30. Blue rock (very hard)	2	119
31. Blue clay	11	130
32. Carbonaceous limestone	20	150
33. Sandstone ("contains some gas")	42	192
34. Shale	12	204
35. Blue rock	3	207
36. Blue clay	2	209
37. Blue rock	3	212
38. Blue clay	13	225
39. Sandstone (gas)	7	232
40. Green shale	25	257
41. Sandstone (gas)	7	264
42. Dark shale	6	270
43. Sandstone (water)	33	303
44. Carbonaceous limestone	5	308
45. Blue shale	6	314
46. Sandstone	21	335
47. Rock concrete (conglomerate)	37	372
48. Gray rock (gas)	13	385
49. Blue shale	45	430
50. Black muck	5	435
51. Blue clay	16	451
52. Limestone	5	456
53. Blue shale	5	461
54. Black gumbo	6	467
55. Blue shale	12½	489½
56. Gray sandstone	4½	504
57. Salt sandrock	22	526
58. Shale	136	662
59. Rock (water)	22	684
60. Blue clay	2	686
61. Rock (oil)	8	694
62. Dark-blue clay	8	702
63. Hard sandstone	18	720
64. Soft rock (water)	6	726

The upper coal (No. 11) is the one mined near Belknap, and the lower seam (No. 26) is probably the stratum seen in the banks of the river (p. 73). Beds 47 to 56 are believed to represent the outcrop shown in the banks of Salt Creek at Graham. (See section, p. 19.) Indications of gas and oil were reported at several horizons, but not in commercial quantities.

One mile northwest of Murray post office a well put down in 1900 struck gas at a depth of 364½ feet. Pressure has decreased since the well was first opened, but in 1907 the escape was sufficient to furnish a blaze about 18 inches high.

In the eastern part of the county the indurated beds consist principally of sandstones and some conglomerates interbedded with blue and yellow clays. At a number of places outcrops of thin beds of limestone were observed. These belong near the base of the Cisco formation. There are several of these limestone beds, ranging from a few inches to 1 or 2 feet in thickness and interbedded with shales. The southeastern part of the county is underlain by sandstones and conglomerates and a few thin beds of limestone interbedded with blue and yellow clays. These rocks rest upon the limestones of the Canyon formation, small exposures of which appear in the banks of the Salt Fork of the Brazos, in the extreme southeast corner of the county. The country is much dissected by erosion, the hills being for the most part capped by conglomerate.

WATER CONDITIONS.

Water for domestic use is obtained largely from cisterns and shallow wells. The wells derive their supplies from the residual sands or upper portions of the sandstones. In many places the underground waters are unsatisfactory and supplies are difficult to obtain. Creeks and storage tanks are relied upon for stock.

Many of the sandstones of the Cisco are porous and contain abundant supplies of water, but for the most part the water is more or less impregnated with sodium chloride and other mineral salts, although a few wells of moderate depth in the sandstone furnish water of fair quality. Salt Creek owes its name to the fact that during dry seasons salt was found incrusting the rocks and gravel in the bed of the stream. The water found in quantities in the deep well put down at Graham (p. 74) is reported to contain 22 to 25 per cent of salt. The largest supply of water is found at a depth of 200 to 300 feet. No flowing wells are known in this locality, the water in the deep wells rising no higher than 30 feet from the surface.

Samples from a number of wells were analyzed in the Survey laboratory, with the results shown in the following table:

Analyses of water from wells in Young County, Tex.

[Parts per million.)

	1	2	3	4	
Silica (SiO_2)	7.6	13	12	8.4	14
Iron (Fe)	4.0	1.8	Tr.	.45	Tr.
Calcium (Ca)	898	554	83	504	116
Magnesium (Mg)	230	534	16	222	46
Sodium (Na) and potassium (K)	7,316	166	70	295	164
Carbonate radicle (CO_3)	.0	.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	164	445	339	242	354
Sulphate radicle (SO_4)	42	2,934	55	1,887	154
Chlorine (Cl)	13,580	293	56	158	245
Nitrate radicle (NO_3)	2.2	8.2	4.2	16	28
Turbidity	(a)	.....	5	(a)	.0
Total solids	22,579	[b] 5,334	451	3,223	945
Date of collection	December, 1906	February, 1907	December, 1906	December, 1906	October 11, 1906

[a] A slight turbidity, probably due to precipitation of iron after collection of sample.
[b] Phosphate radicle (PO_4), 0.0.

1. Judge R. F. Arnold's well, Graham; depth, 110 feet. W. M. Barr, analyst.
2. Barber shop well, Graham; depth, 61 feet. H. S. Spaulding, analyst.
3. John C. Kay's well, Graham; depth, 65 feet. W. M. Barr, analyst.
4. Well on lot 10, block 11, Graham. W. M. Barr, analyst.
5. Pandy's well, 3 miles southeast of Spring Creek; depth, 20 feet. W. M. Barr, analyst.

The following notes on the quality of these waters have been furnished by R. B. Dole, chemist, United States Geological Survey:

1. Probable scale-forming ingredients, nearly 3,000 parts per million; foaming ingredients, 20,000 parts; water is probably corrosive. This is a sodium-chloride water, unfit for boiler use, for irrigation, or for water supply.

2. Probable scale-forming ingredients, 2,500 parts per million; foaming ingredients, 450 parts; water is probably corrosive. This is a calcium-sulphate water, which would be bad for domestic use on account of its high mineral content. Its high scale-forming content and the probability of corrosion make it very bad for boiler use; if it were purified by the use of lime and soda ash, the foaming ingredients would thereby be increased to a degree almost prohibitive. The water could be called only fair for irrigation.

3. This seems to be the best water. It is a calcium-carbonate water of moderate mineral content and fair for boiler use. It could be improved by softening. The probable scale-forming ingredients are 280 parts per million; foaming ingredients, 190 parts; water is noncorrosive. It would be entirely acceptable for use in irrigation.

4. Calcium-sulphate water of high mineral content; probable scale-forming ingredients, 1,800 parts per million; foaming ingredients, 800 parts; water is probably corrosive. This water is unfit for boiler use without purification and softening, which would increase the foaming ingredients and render the water likely to foam badly. It is potable but would probably have a distinct "gypsum" taste. It probably could be used for irrigation on loose sandy soils where there would be good opportunity for thorough underdrainage.

5. A water of fairly high mineral content; probable scale-forming ingredients, 430 parts per million; foaming ingredients, 440 parts; corrosion uncertain; water bad for boiler use in its raw state, but could be purified. It would be acceptable for domestic use but would be considerably harder than No. 3. The remark on No. 4 regarding its use for irrigation applies to No. 5.

There are few springs in the county, and none of any importance as a source of water supply.

There is scarcely any probability that flowing wells can be obtained in this county, except possibly at a few localities in the eastern part. Wells put down to the basal beds of the Cisco formation find supplies of water which in a few places may reach the surface. The limestones of the Canyon formation should be reached in the eastern part of the county at depths of 250 to 500 feet. Farther west they lie at greater depths from the surface, possibly at 800 to 1,000 feet. Aside from the fact that the water would probably not rise to the surface, the unfavorable prospects for obtaining desirable deep-seated supplies in this part of the county are enhanced by the probability that with the increased distance from the outcrop the water would become too highly impregnated with mineral matter for use.

JACK COUNTY.

PHYSIOGRAPHY.

Jack County, which adjoins Young County on the east, is rectangular in shape and has an area of 858 square miles. Its population is 11,817 (1910). The mean annual rainfall is 33 inches. The county seat is Jacksboro.

The surface of the county is made up of hills and ridges, interspersed with broad valleys and plateaus. The striking features of the topography of this county are the broad, flat prairies flanked by hills and ridges, a result of the varying resistance offered to erosion by the different rock formations. Northeast of Jacksboro the hills are capped by sandstone and conglomerate; the valleys are located upon the more easily eroded limestones.

The larger part of the county is drained mainly by the West Fork of Trinity River, which enters at the northwest corner and flows in a southerly direction across the county. A small area in the southern part of the county is drained by small tributaries of the Salt Fork of the Brazos.

GEOLOGY.

All three of the formations of the Pennsylvanian in Texas, the Strawn, Canyon, and Cisco, outcrop within the boundaries of Jack County. The Strawn underlies a small triangular area in the southeast corner of the county; the northern and western portions, constituting more than half of the county, are underlain by the Cisco. The intervening belt is occupied by the Canyon formation. All these formations dip toward the northwest at approximately 30 to 40 feet to the mile.

The character of the Cisco is much the same as in Young County. Sandstones, shales, and conglomerates, with a few limestones, constitute most of the formation. Coal outcrops in places in the valley of the West Fork in the northern part of the county. A drill hole put down in 1900 to a depth of 340 feet on the land of D. L. Knox on

Lost Valley Creek, near Squaw Mountain, failed to penetrate the Cisco formation. Three water-bearing beds were passed through, the first at a depth of 130 feet, the second at 189 feet, and the third at 228 feet. The water, which is of fairly good quality, flows out at the surface. Shales and sandstones make up the larger part of the section, as shown by the following record furnished by the owner, Mr. D. L. Knox, of Jacksboro:

Record of well on Lost Valley Creek, near Squaw Mountain, Tex.

	Thickness.	Depth.
	Ft. in.	*Ft. in.*
Soil and yellow clay	8	8
Yellow "soapstone"	16	24
Red "soapstone"	8	32
Light-blue "soapstone"	14	46
Blue limestone	9	55
Blue "soapstone"	24	79
Coal	8	79 8
Blue clay	3	82 8
Sand and "soapstone"	8	90 8
Red "soapstone"	7	97 8
Blue "soapstone"	4	101 8
Red "soapstone"	6	107 8
Blue "soapstone"	8	115 8
White sandstone; first flow of water	15	130 8
Blue "soapstone"	2	132 8
Red "soapstone"	6	138 8
Blue "soapstone" and sandstone	7	145 8
Red "soapstone" and sandstone	8	153 8
Blue "soapstone" and sandstone	10	163 8
Red sandstone	2	165 8
Blue "soapstone" and sandstone	13	178 8
White sandstone; second flow of water	11	189 8
Blue "soapstone"	9	198 8
White sandstone; third flow of water	30	228 8
Blue sandy "soapstone," with vegetable matter, and thin layers of sandstone one-half inch to 8 inches thick	111 4	340

The well starts below the coal, which outcrops at the foot of Squaw Mountain. The coal has been mined to some extent for local use.

The following record of a boring made for oil on the Bazette ranch, 10 miles a little east of north of Jacksboro on the Postoak road, has been furnished by Mr. Charles A. Lee.

Record of boring for oil on Bazette ranch, 10 miles north of Jacksboro, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
1. Surface soil	5	5
2. Black shale	95	100
3. Sand with some oil; in other near-by wells this sand appears to be 10 to 12 feet thick; yielded 3 gallons of oil a day	6	106
4. Sand with salt water	10	116
5. Shale and some sand	134	250
6. Running sand, with salt water	10	260
7. Unknown, record missing	230	490
8. Hard sandrock; oil with salt water under it	10	500
9. Shale with shells	100	600
10. Hard crystalline limestone	50	650
11. Conglomerate, soft	5	655
12. White crystalline limestone	100	755
13. Sandstone and shale	35	790
14. Sandstone saturated with oil and gas	10	800
15. Black shale	50	850
16. Shale and "rock"	40	890
17. Unknown	10	900
18. Sandstone with gas; pressure sufficient to throw water over derrick shed; not penetrated	30	930

The upper 600 feet of this section apparently belongs to the Cisco, and the remainder (Nos. 10 to 18) to the Canyon formation. Several borings were made in this vicinity in the search for oil. A small amount of oil and some gas were found.

Jacksboro is located on the western margin of the outcrop of the Canyon formation. The limestone beds exposed are about 20 feet thick and belong to the upper series (No. 10) shown in the foregoing section. In the Texas reports [1] they are called the Campophyllum beds, from the great number of the cup coral (*Campophyllum torquium*) that they contain. These beds are underlain by 5 to 75 feet of sandy clays and sandstones, locally conglomeratic, called by Drake the Bluff Creek bed. Below this in the Colorado coal field, as shown by Drake, are five series of limestones, each 25 to 75 feet thick, separated by corresponding thicknesses of clays and sandstones. The wells put down at Jacksboro show a greater proportion of clays and less limestone than in the region farther south. A quarry, located near the track of the Chicago, Rock Island & Gulf Railway at Jacksboro, is operated by the railroad company for ballast material. The beds furnish a good building stone, which has been used for some of the most prominent structures in the town. The rock is a hard bluish-gray compact fossiliferous limestone. The upper strata are rather irregular in bedding. The lowest stratum quarried is a dark-blue limestone about 15 inches in thickness, and from this stratum the best building stone is obtained.

A number of wells have been put down in the town, the records of some of which follow:

Record of well of Judge Horton, in the western part of Jacksboro, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	35	35
Blue shale	15	50
Limestone	16	66
Dark-blue shale or clay, with two or three streaks of limestone	139	205
Sand and blue shale ("mixed with oil")	20	225
Shell formation, with salt water	2	227
Sand and salt water	27	254
Blue shale (not penetrated).		

Record of well of M. W. Cooper, near center of Jacksboro, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	52	52
Limestone	22	74
Blue shale	25	99
Clay	14	113
Shale	20	133
Limestone	10	143
Shale	57	200
Shale and sand ("some sulphur")	12	212
Blue shale (not penetrated)	3	215

[1] Drake, N. F., Report on the Colorado coal field: Fourth Ann. Rept. Texas Geol. Survey, 1892, p. 400.

A well put down in 1899 about 12 miles south of Jacksboro for D. L. Knox, by W. F. Nawatny, gave the following record:

Record of drill hole 12 miles south of Jacksboro, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
1. Soil and earth	6	6
2. Yellow sandstone	20	26
3. "Concrete rock"	2	28
4. Blue soapstone	42	70
5. Red soapstone	20	90
6. Dark-blue soapstone, with hard iron nodules	188	278
7. Hard carbonaceous sandy shale	76	354
8. Soft blue "slate" (caving)	13	367
9. Blue flinty limestone	4½	371½
10. Blue soapstone	2½	374
11. Blue flinty limestone	7	381
12. Blue soapstone	16	397
13. Very hard limestone, with chert and pyrites	30	427
14. Dark streaky limestone	12	439
15. Soft blue soapstone (caving)	22	461
16. Limestone	15	476
17. Gray sandy soapstone	21	497
18. "Limy" sandstone	6	503
19. Soft light-blue to gray streaky soapstone	79	582
20. Sandstone	2	584
21. Flinty limestone	4	588
22. Hard sandstone, honeycombed	12	600

This well evidently starts in rock below any shown in the Jacksboro wells. In comparing this record with Drake's section[1] the following correlation can be fairly well established:

Correlation of Drake's section and record of Knox drill hole, near Jacksboro, Tex.

Drake's section (Canyon division)	Knox drill hole.
12. Campophyllum bed 11. Bluff Creek bed	Not represented.
10. Home Creek bed [limestone] 9. Hog Creek bed [clays and sandstones]	Nos. 2 to 8.
8. Chert bed [cherty limestones]	Nos. 9 to 14.
7. Bed No. 7	Nos. 15 to 18.
6. Clear Creek bed [clay, some limestone]	No. 19.
5. Cedarton bed [sandstone]	No. 20.
4. Adams Branch limestone	No. 21.
3. Brownwood bed [upper sandstone]	No. 22.

On the Lee farm, 9 miles north of Jacksboro, on the West Fork of Trinity River, the Amber Petroleum Co., of Pittsburgh, Pa., sunk a well 2,200 feet deep in prospecting for oil. This well was begun in February and finished in July, 1907. The drillers were Joseph Kerr and Edward Wasson. The record as given by Mr. Kerr follows.

[1] Fourth Ann. Rept. Texas Geol. Survey, 1892, p. 387.

Record of prospect hole of Amber Petroleum Co., 9 miles north of Jacksboro, Tex.

[Diameter of well at mouth, 13 inches; at bottom, $5\frac{1}{8}$ inches.]

	Thickness.	Depth.
	Feet.	*Feet.*
1. Soft yellow earth	30	30
2. Soft black "cement" rock	80	110
3. Soft black sand and gravel	10	120
4. Soft black "cement" rock	85	205
5. Red "mineral rock"	30	235
6. White sand; hardness variable; first water, salt	25	260
7. Soft black "cement" rock	90	350
8. Red rock, caved (probably shale)	10	360
9. Hard gray sand; second water, salt	40	400
10. Soft gray and red "asphalt" rock	175	575
11. Hard red limerock	15	590
12. Soft black broken lime	45	635
13. Dark "asphalt" rock	15	650
14. White sand; salt water (third), and oil	52	702
15. Soft black slate	48	750
16. Sand and slate; salt water (fourth) at 800 feet	100	850
17. "Asphalt" rock	10	860
18. Soft white sand	30	890
19. Hard black "asphalt"	10	900
20. Soft white sand (show of red oil)	60	960
21. Soft dark "asphalt"	$194\frac{1}{2}$	$1,154\frac{1}{2}$
22. Soft white sand; salt water (fifth)	30	$1,184\frac{1}{2}$
23. Soft black slate (thin stratum).		
24. Soft white sand; salt water (fifth)	$70\frac{1}{2}$	1,255
25. Soft black slate	43	1,298
26. Soft black "asphalt"	6	1,304
27. Medium black slate	80	1,384
28. Medium gray sandy lime (show of oil and water)	88	1,572
29. Soft white sand; salt water (sixth) in upper part	103	1,675
30. Hard gray lime (almost flint)	25	1,700
31. Medium black slate	75	1,775
32. Hard gray sandy shale	40	1,815
33. Soft black slate	85	1,900
34. Very hard gray sand	30	1,930
35. Soft white slate	50	1,980
36. Soft black slate	80	2,060
37. Shelly brown and gray sand (smelled of oil and gas)	30	2,090
38. Soft white slate	110	2,200

The rock called "asphalt" by the driller was so named because of its "smell and from the fact that it mixed with water." It was probably clay impregnated with oily matter. A clearly recognized bed in the record is the "cherty limestone" of the Canyon (No. 30). Beds Nos. 11 and 12 are apparently the top beds of the Canyon; and if so, the section would be interpreted as Cisco from 1 to 10, inclusive, 575 feet, and Canyon for the remainder. The sandstones of the Strawn were not reached. Two facts of interest in this section are the great increase in thickness of the Canyon (from about 800 feet on the Colorado to over 1,645 feet on the West Fork of the Trinity) and the thinning out of the limestones, their place being taken by clays. It is of interest to note also that the "cherty bed" of the Canyon (No. 8 of Drake's section) is an excellent guide in the classification of well records in this region. The large amount of chert contained makes it the despair of the driller and leaves little doubt of its identity. It seems to have been the source of the cherty pebbles so abundant in some of the conglomerates of the Cisco.

In its northeastward extension the Canyon formation passes from sight beneath overlying beds several miles east of Cundiff.

The Strawn formation occupies all that part of the county southeast of the Canyon area. The formation has a thickness of about 4,000 feet and consists principally of sandstones alternating with thinner beds of blue clay.

WATER CONDITIONS.

Over a considerable part of the Cisco area the water conditions are essentially the same as in Young County. Water for domestic use is obtained from wells of moderate depth, generally in a porous sandstone, though locally in the overlying residual sands and clays. The water is likely to be charged with mineral matter, especially in the deeper wells. The part of the county underlain by the Cisco contains three areas in which flowing wells may be obtained. One is in the vicinity of Squaw Mountain, where there is a flowing well, the record of which is given on page 79. The second is at Gertrude; and the third is in the vicinity of Jeannette, 7 miles west of Jacksboro. In none of these wells is the flow strong. The wells all draw their supply apparently from a sandstone near the base of the Cisco formation. Flowing wells in the southeast corner of Stephens County are supplied essentially from the same horizon. Whether flows could be obtained in the intervening belt has not been determined, but such data as are available indicate that they could not. In most wells in the region the water rises less than 50 feet above the bed in which it occurs. In the Cisco belt, however, it rises from 100 to 350 or 360 feet. For example, the Squaw Mountain well is 340 feet deep and the water is said to have overflowed from a pipe 18 to 20 feet above the curb. The flowing wells at Gertrude are from 118 to 130 feet deep; how far the water from them will rise above the surface is not known. At Jeannette two flowing wells are reported, one 96 feet deep, the other 105 feet.

In the vicinity of Antelope dug wells are from 20 to 60 feet deep, and larger supplies are found at depths of 90 to 150 feet, but there are no flowing wells. In wells 150 feet in depth the water is said to rise within 70 feet of the surface. The water of some of the shallow wells is of good quality; in others it is too highly mineralized for use. The deeper waters usually show a higher content of mineral salts, and some of them are so salty that they are not available for domestic use or even for stock.

Springs are of rare occurrence in the Cisco area. In the vicinity of Antelope there are several springs in the sandrock, one of which, on the farm of Mr. Adkins, is reported to be of considerable size.

The Canyon formation constitutes the most important water-bearing formation in the area studied. The limestones contain water in caverns and underground solution channels. These are the source of numerous springs which appear along the outcrops of the beds, at the contact with the underlying shale. (See Pl. II *B* p. 60.) The occurrence of such cavities and passages, however, is very irregular, and although deep wells in limestone regions are likely to strike one or more such passages there is much uncertainty as to the outcome.

Most of the wells in this area find water in the sands that are interbedded with the limestones. The principal water bed at Jacksboro is reached at depths of 145 to 230 feet. This is between the second and third limestones from the top of the Canyon formation. The beds included between the first and second limestones are locally water bearing, and some wells find their supplies at this horizon. M. W. Cooper, who has drilled many wells in this vicinity, states that the records will average about as follows:

General section of deep wells at Jacksboro, Tex.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	4	4
Sandrock	8	12
Clay	20	32
Blue shale	4–20	52
Limestone	18–28	80
Shale, in some wells containing sand and water	80	160
Limestone	10–16	176
Shale	5–15	191
Sandstone, chief water bed	40	231

The water rises within about 75 feet of the surface in the deeper wells. In early days, according to Mr. Cooper, many of the wells flowed, but there are now no flowing wells in the town. The average depth of the wells is from 160 to 175 feet, depending on the location of the top and the differences in thickness of the beds. The water-bearing sand (No. 9) is not uniformly developed and is reported to thin out toward the east and north. In some wells the second limestone (No. 7) is replaced by sands and shales impregnated with oil, and the water found at this horizon is usually of bad quality. In some wells located on low ground the water flows out at the surface.

The water in many of the wells at Jacksboro shows marked differences in quality within short distances. A black oily substance is sometimes encountered in the upper part of the sandstone formation, but in the lower part of the beds good water may be found. The only attempt to find water supplies in deeper beds in this vicinity

was that of D. L. Knox, who sunk a well at his residence to a depth of 550 feet. The main water bed appears to be absent here, and the water at deeper horizons was found to be highly impregnated with salt. Although the amount of potable water available at the main horizon is considerable, it is insufficient to meet the demands made upon it by the growth of the town, and this, coupled with the fact that in so many wells the water is unfit for use, will soon make it necessary to consider the possibility of other sources of supply. As to this problem the data at hand offer little light. So far as known the Jacksboro water horizon is one of the best in the series. As in beds at other horizons, however, the water is affected locally by injurious ingredients, and as the beds dip westward under cover the water doubtless becomes more highly mineralized. As to water from deeper horizons, the data in hand indicate that though abundant, it is almost sure to be saline.

In the western part of the Canyon area the conditions will be found much the same as at Jacksboro. Throughout most of this belt the Jacksboro water horizon will doubtless yield ample supplies. The conditions as to depth and pressure will manifestly vary with the locality. On the east this belt is bounded by the outcrop of the cherty limestone beds.[1] The areas farther east were not included in the present investigation, but the data available indicate that the water from deep wells in that region is likely to be more or less affected by mineral salts.

Thomas Owen, living 2 miles southeast of Adieu, has a well 300 feet deep. He reports the following record:

Common earth about 15 feet, soapstone for about 82 feet, and struck a gray sandstone with water, which came up about 36 feet in the well. Continued boring but found no more water and finally struck a hard white rock into which the boring was continued for 20 feet.

This water-bearing sandstone was doubtless the same as that in the wells at Jacksboro and the "hard white rock" the cherty limestone which underlies it.

Gibtown is situated in the southeast corner of the county, on the outcrop of the Strawn formation. In this vicinity water for domestic use is obtained from open and drilled wells ranging in depth from 20 to 65 feet. The supplies are found in the superficial portion of the sands of the Strawn formation. The water is said to be hard, and the supplies are ample for the present needs of the community.

Analyses of waters from a number of wells in Jack County are given on page 86.

[1] These beds are those designated No. 8 in Drake's report on the Colorado coal field (Fourth Ann. Rept. Texas Geol. Survey, 1892, p. 395).

Analyses of ground waters in Jack County, Tex.

[Parts per million. Analyst, B. L. Glascock. Samples collected Sept. 24, 1907.]

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	12	20	32	15	14	10	2.5	10	5.0	5.0
Iron (Fe)	.94	.9	.62	.7	.75	.75	.8	.8	.85	.8
Aluminum (Al)	2.0	3.0	2.4	.5	1.3	2.3	1.3	2.0	1.0	1.3
Calcium (Ca)	10	20	105	197	224	8.5	9.0	26	102	96
Magnesium (Mg)	3.0	3.5	54	138	153	3.0	11	11	31	33
Sodium (Na)	330	963	114	1,040	1,109	291	293	944	664	689
Potassium (K)	8.0	13	7.8	13	15	5.3	34	12	132	15
Carbonate radicle (CO_3)	14	22	7.2	7.2	.0	4.8	29	7.2	.0	.0
Bicarbonate radicle (HCO_3)	517	610	439	756	766	659	669	549	224	266
Sulphate radicle (SO_4)	137	166	303	1,590	1,758	80	100	231	1,603	1,468
Nitrate radicle (NO_3)	1.8	1.33	.44	4.9	1.33	1.33	3.1	3.1	.44	1.1
Chlorine (Cl)	139	1,040	55	795	870	37	50	1,125	181	115
Total solids	907	2,568	922	4,190	4,595	758	844	2,766	2,806	2,513
Turbidity	0	0	0	0	0	0	0	0	0	0

1. Well of J. R. Edmondson at Jeanette, Tex.
2. Well of the postmaster at Finis, Tex.
3. Vineyard mineral water at Vineyard, Tex.
4. Helm's well, 12 miles east of Jacksboro, Vineyard, Tex.
5. Well of W. L. Vesner, at Vineyard, Tex.
6. Well of W. F. Worden, 1 mile west of courthouse, Jacksboro, Tex.
7. Well of H. Hensley, 1½ miles west of courthouse, Jacksboro, Tex.
8. Well at Phipp's place, 2 miles northeast of courthouse, Jacksboro, Tex.
9. Hensly & Johnson's farm well at Hess, Tex.
10. Well at Hannible Pass place, Hess, Tex.

The following notes regarding the usefulness of these waters have been prepared by R. B. Dole, chemist, United States Geological Survey:

1. Estimated scale-forming ingredients, 50 parts per million; foaming ingredients, 900 parts; water is noncorrosive, but would foam in boilers. It is high in mineral content, especially in alkalies, and would be poor in irrigation; it is potable.

2. Very high in mineral content and unsuitable for use.

3. A sulphate and carbonate water of rather high mineral content but notably lower in alkalies and in chlorides than most of the other waters. Estimated scale-forming ingredients, 450 parts per million; foaming ingredients, 350 parts; water is noncorrosive; good for irrigation; hard, but potable.

4 and 5. Sodium sulphate waters of very high mineral content and unfit for use except possibly for irrigating land where thorough drainage and other precautions to prevent accumulation of alkali have been adopted.

6 and 7. Sodium carbonate waters of moderately high mineral content and similar composition; poor for irrigation; low in scale-forming ingredients but too high in foaming ingredients to be suitable for boilers.

8. A water of very high mineral content; unsuitable for use in boilers or for irrigation, and too salty to be good for domestic use, though drinkable.

9 and 10. Sodium sulphate waters of very high mineral content and similar composition; would foam in boilers; potable but not very good for domestic use; poor for irrigation.

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